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science for a changing world

Lake Erie HABs and Hypoxia:

Effects of Nutrient Loading and Changing In-Lake Dynamics

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USGS– Great Lakes Science Center

U.S. Department of the Interior
U.S. Geological Survey

Four goals

- An organizing method for scientific information
- Both in lake and external loading changes matter
- Form of phosphorus matters
- Multiple causes and multiple effects must be considered to understand the system

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Context

- Problems often have multiple causative steps between factors we can control and outcomes we care about
- More steps for economic costs of control attempts, outcomes, or both
- Controls, outcomes, and costs can be dispersed in space and time, making the links hard to think about

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One solution: graphical function mapping

- In math, “mapping” one function onto another used to graphically track the cumulative impact of many “steps”

- can be used for environmental science and management questions to stimulate thought and discussion

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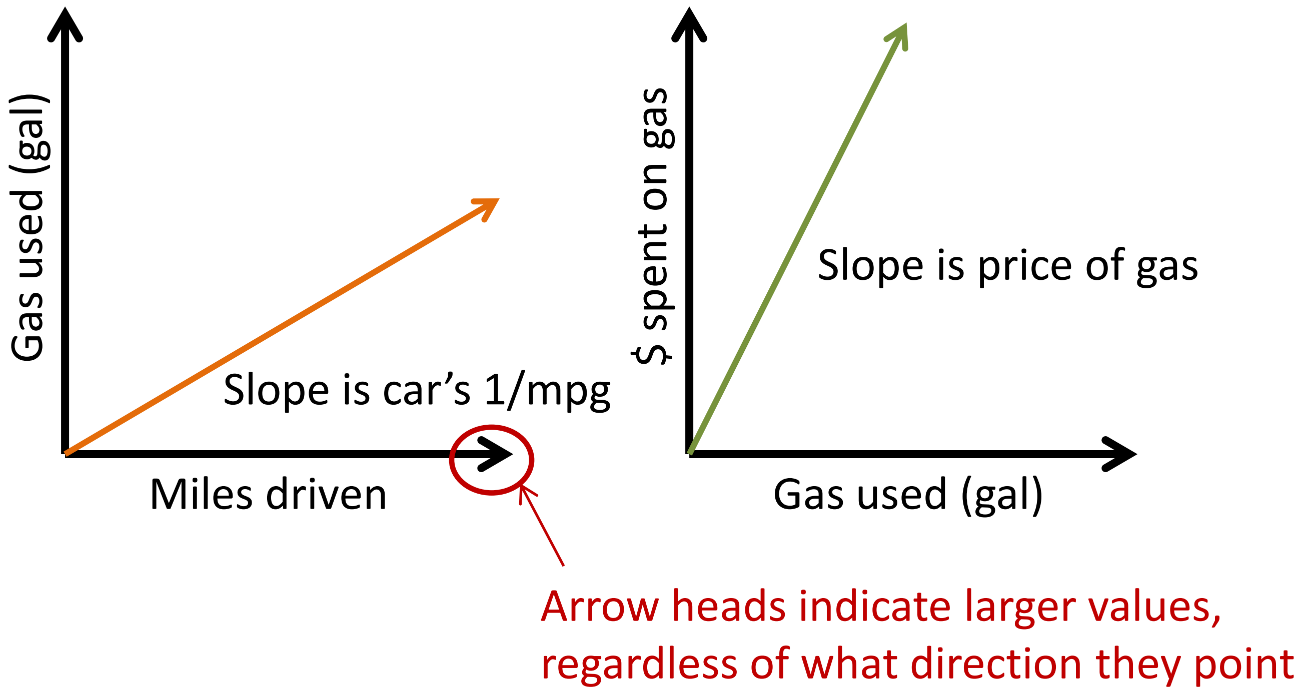
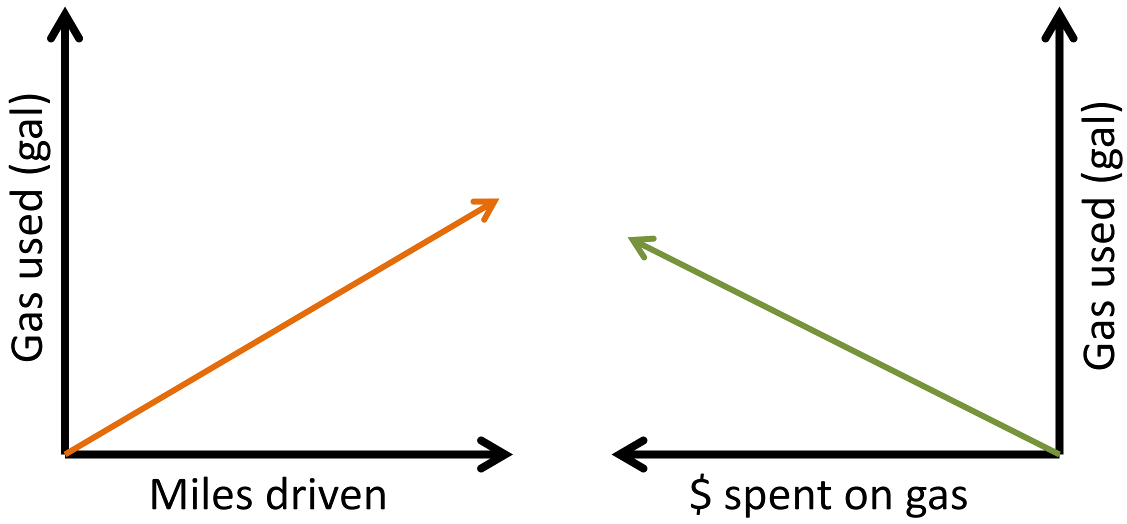
Function mapping, generic

- Using some familiar, linear functions



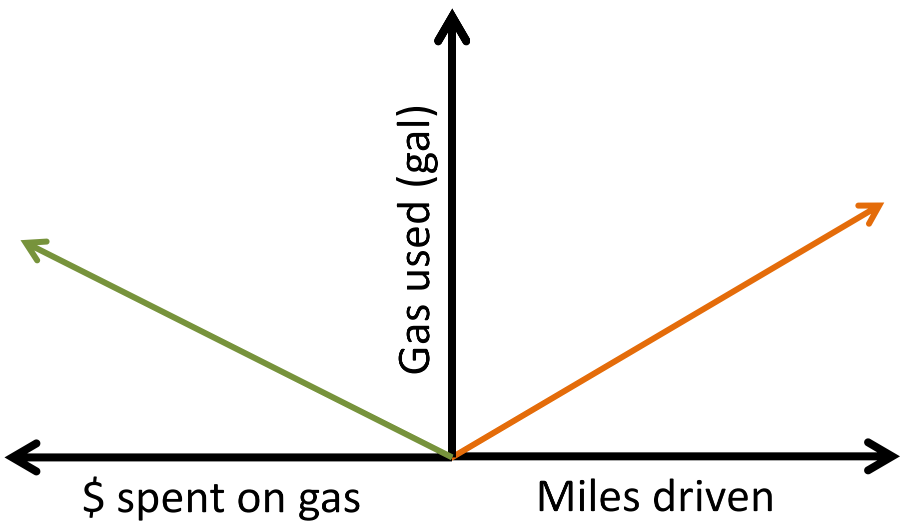
Function mapping, generic

- Using some familiar, linear functions
- Rotate, align



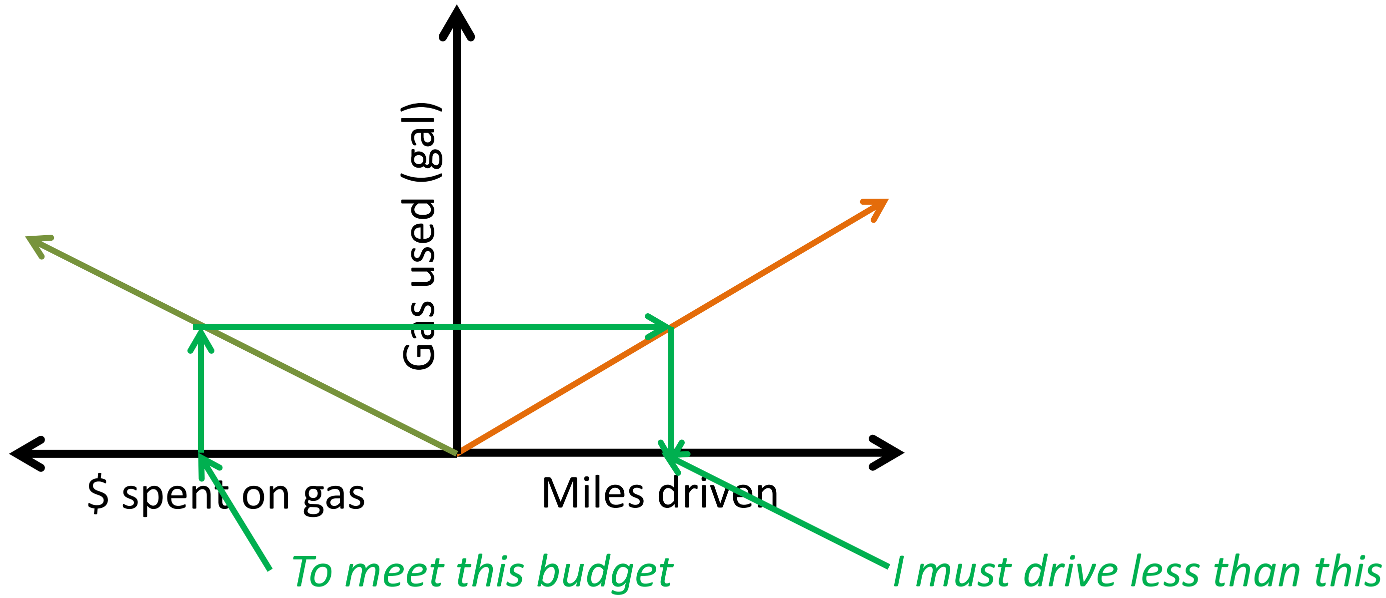
Function mapping, generic

- Using some familiar, linear functions
- Rotate, align, and join graphs



Function mapping, generic

- Using some familiar, linear functions
- Rotate, align, and join graphs
- Map outcomes: backward, forward, or conditional



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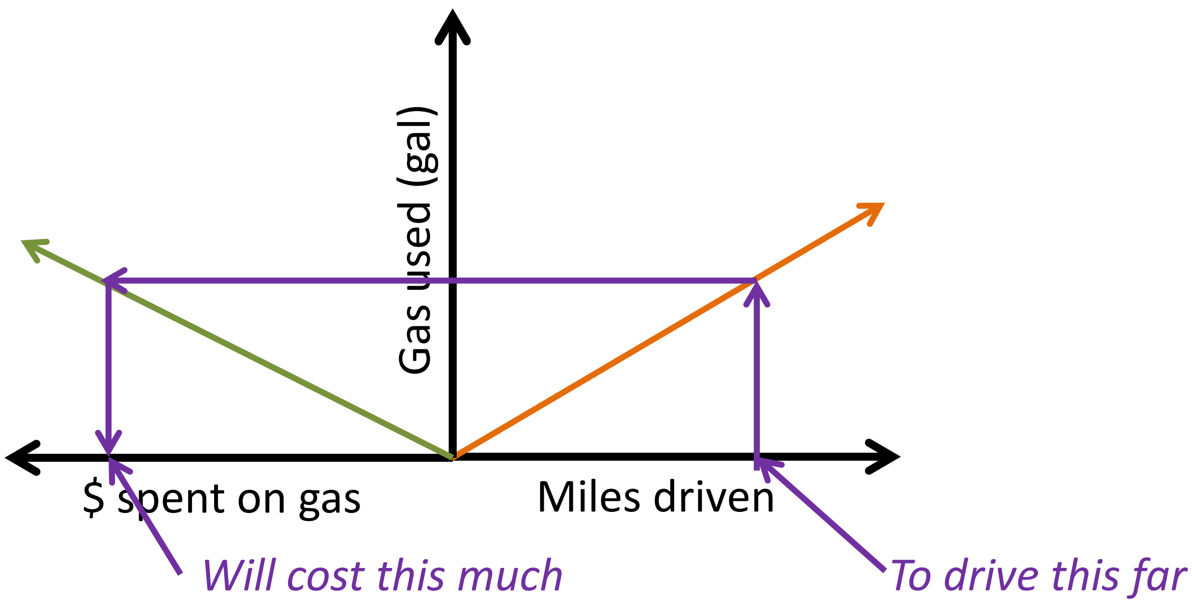

Function mapping, generic

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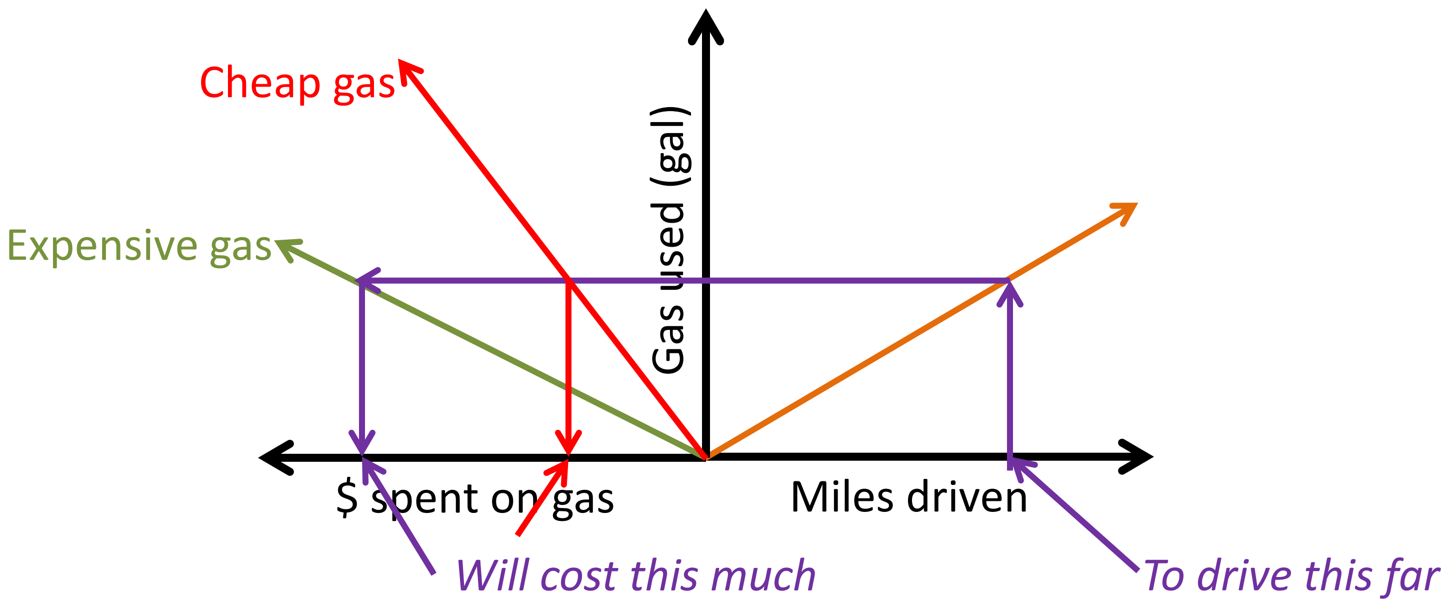
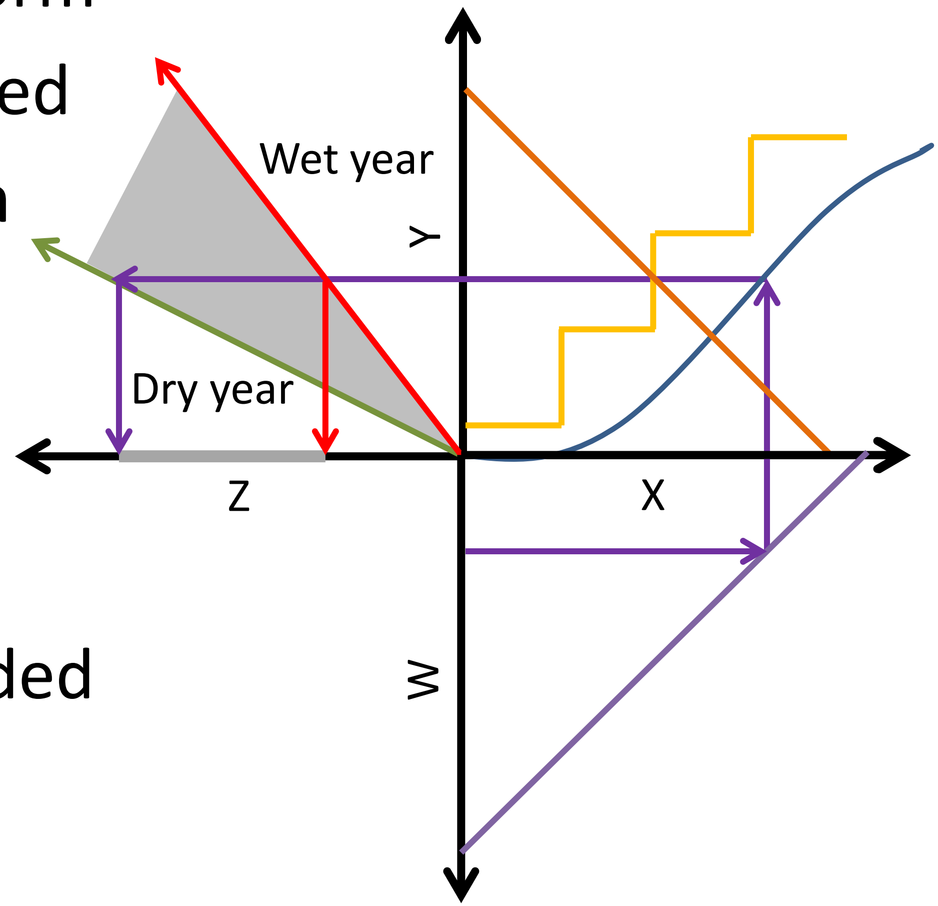


Function mapping, generic

- Functions can take any form
- More "steps" can be added
- Functions can come from
  - Empirical observations
  - Expert judgment
  - Simple correlations
  - Complex models
- Uncertainty can be included



Uses

- Discussion tool
  - Collective drawing as a way to talk across disciplines and stakeholder groups
- Finding the “weak link” where more knowledge is needed
- Finding targets for management and indicators of success
  - Some axes are easier to manage than others
  - Some axes are easier to monitor than others
  - Selecting monitoring indicators in a causative path can be more powerful than statistical indicators

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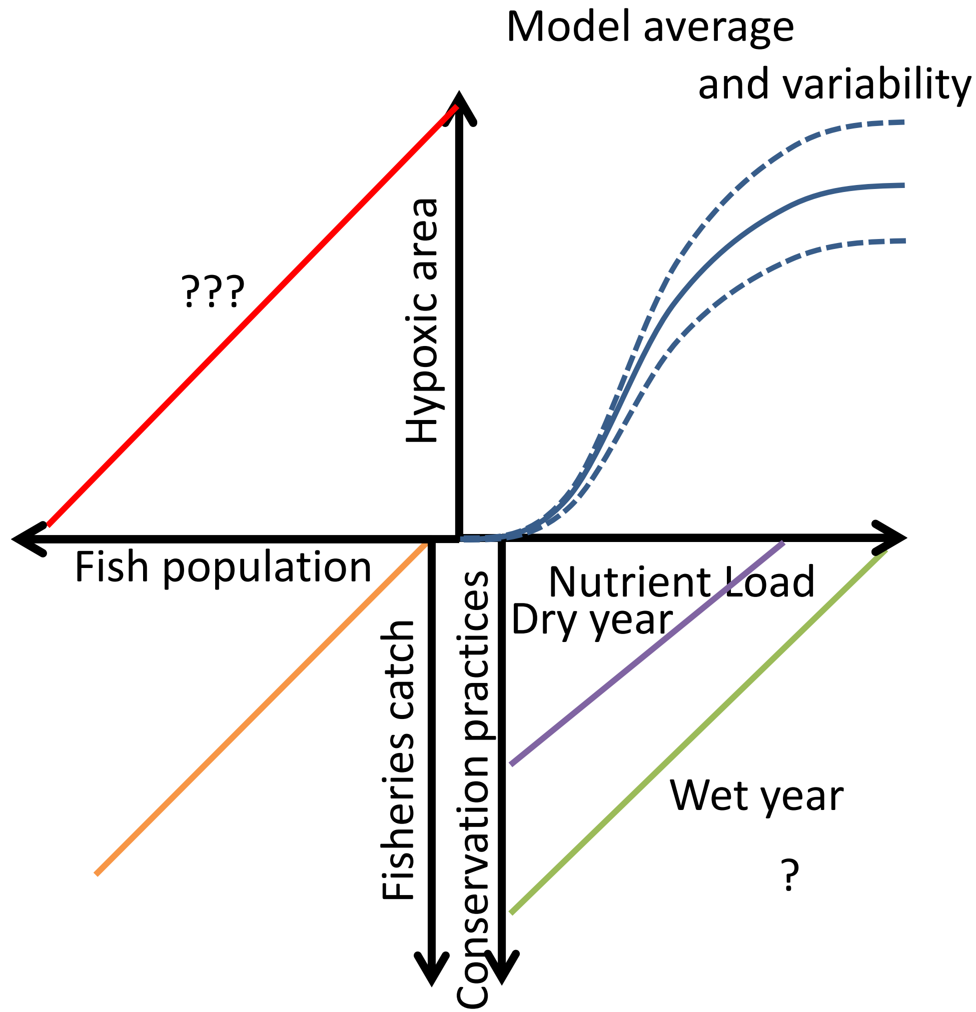
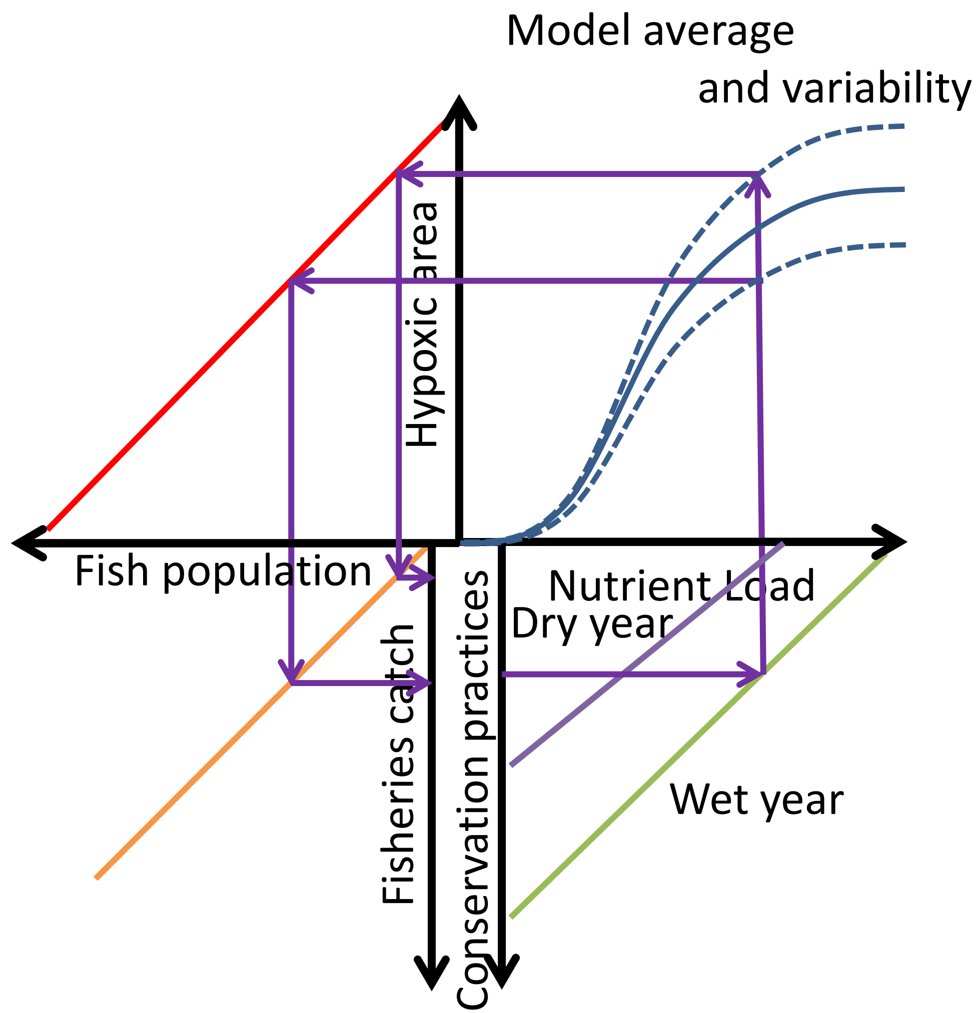
The goal, Lake Erie hypoxia

- Connection between nutrient load and hypoxic area
  - measures of variability
- What controls nutrient load
  - Wetland area
  - Rain fall
  - Other things too…
- Effects on fish
  - Discussions show this relationship is particularly uncertain
- Map!



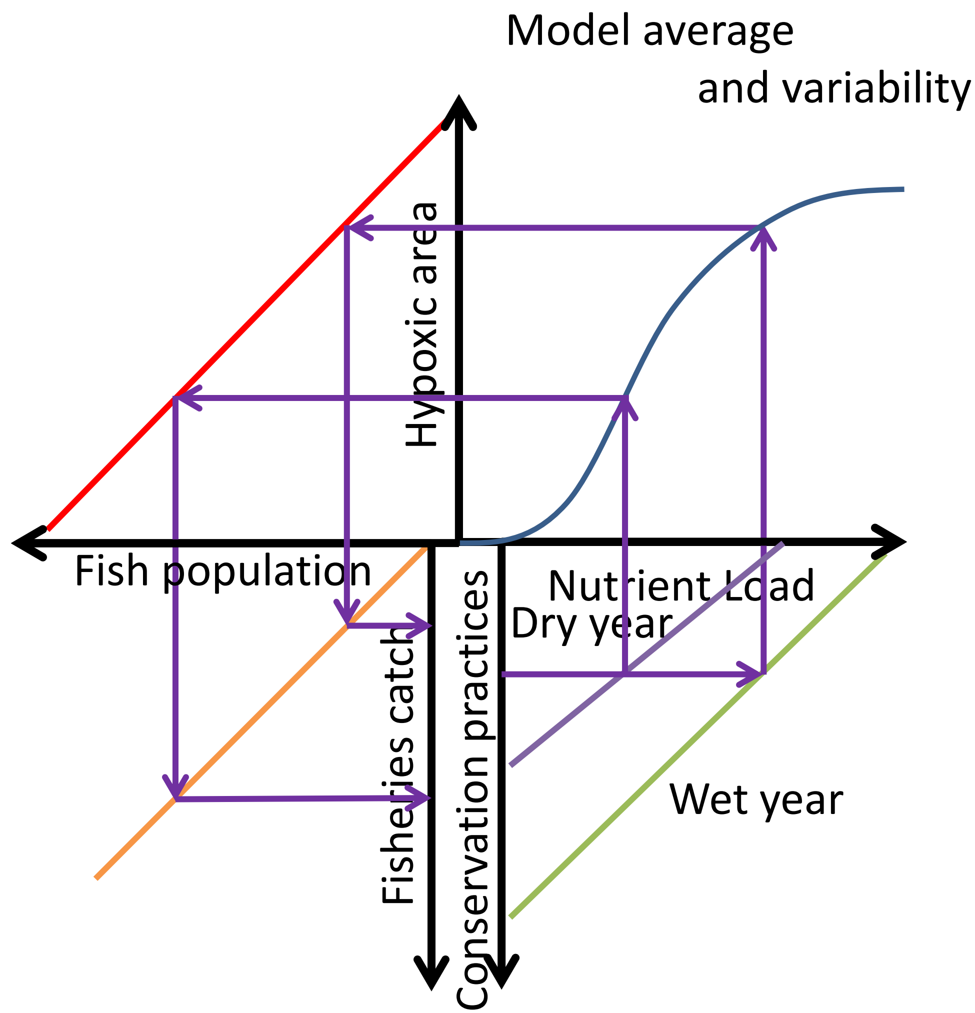
The goal, Lake Erie hypoxia

- Map variability effects



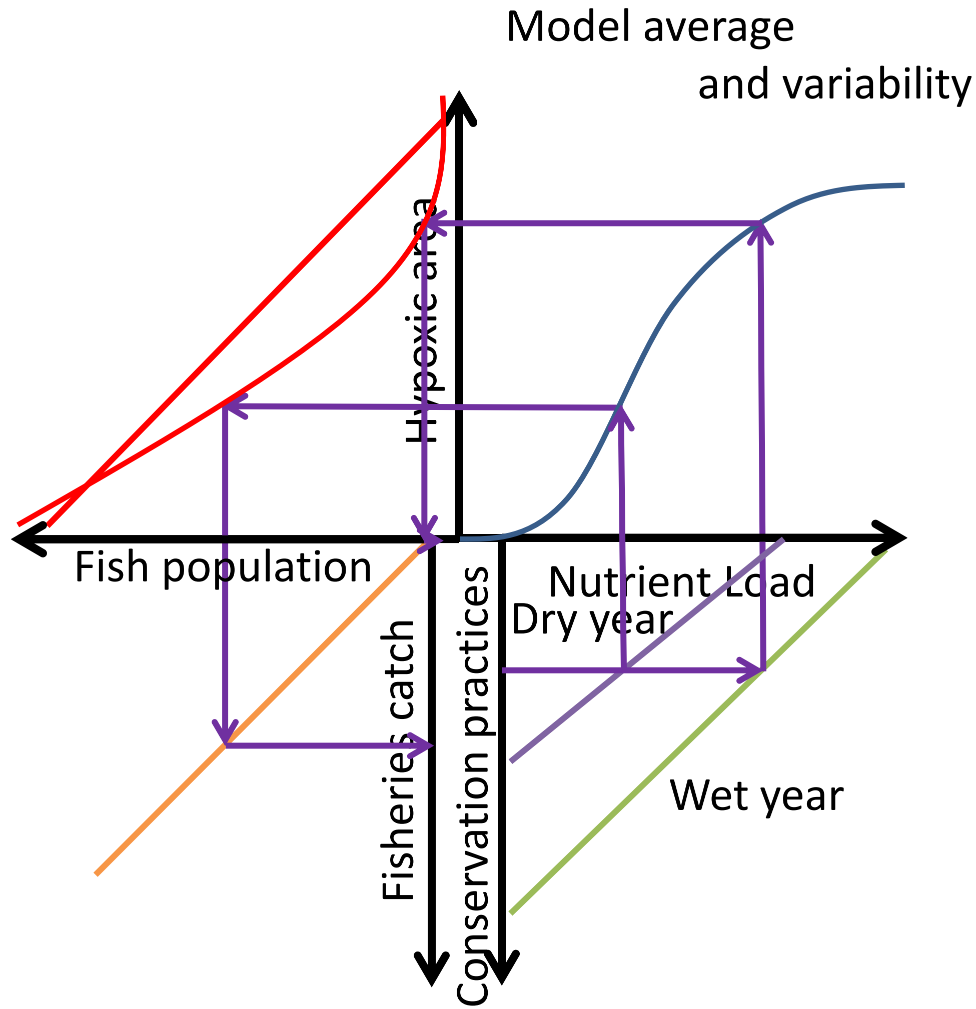
The goal, Lake Erie hypoxia

- Map variability effects
- Map wet vs. dry year



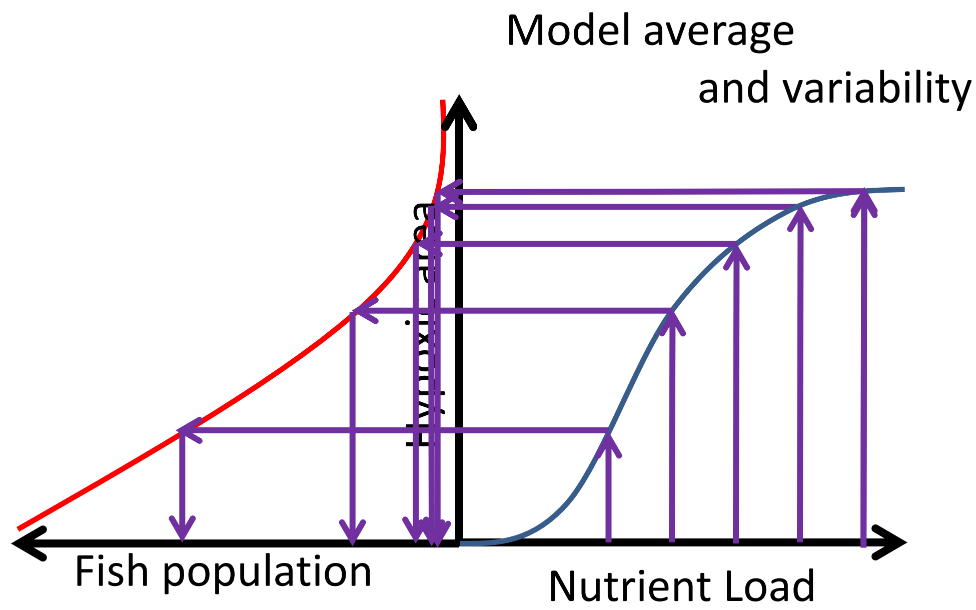
The goal, Lake Erie hypoxia

- Map variability effects
- Map wet vs. dry year
- Map alternative fish response functions

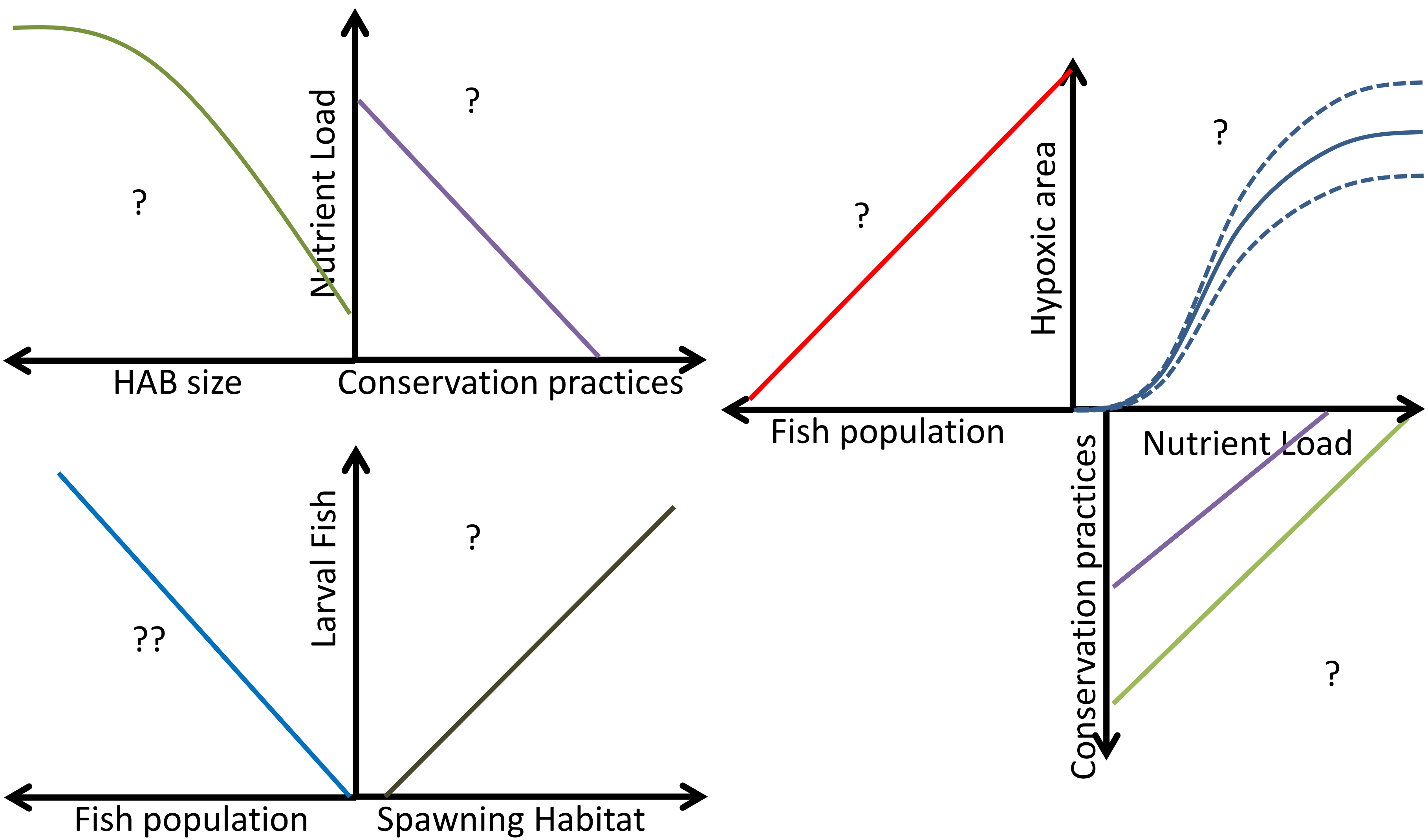


The goal, Lake Erie hypoxia

- Map variability effects
- Map wet vs. dry year
- Map alternative fish response functions
- Explore non-linear effects



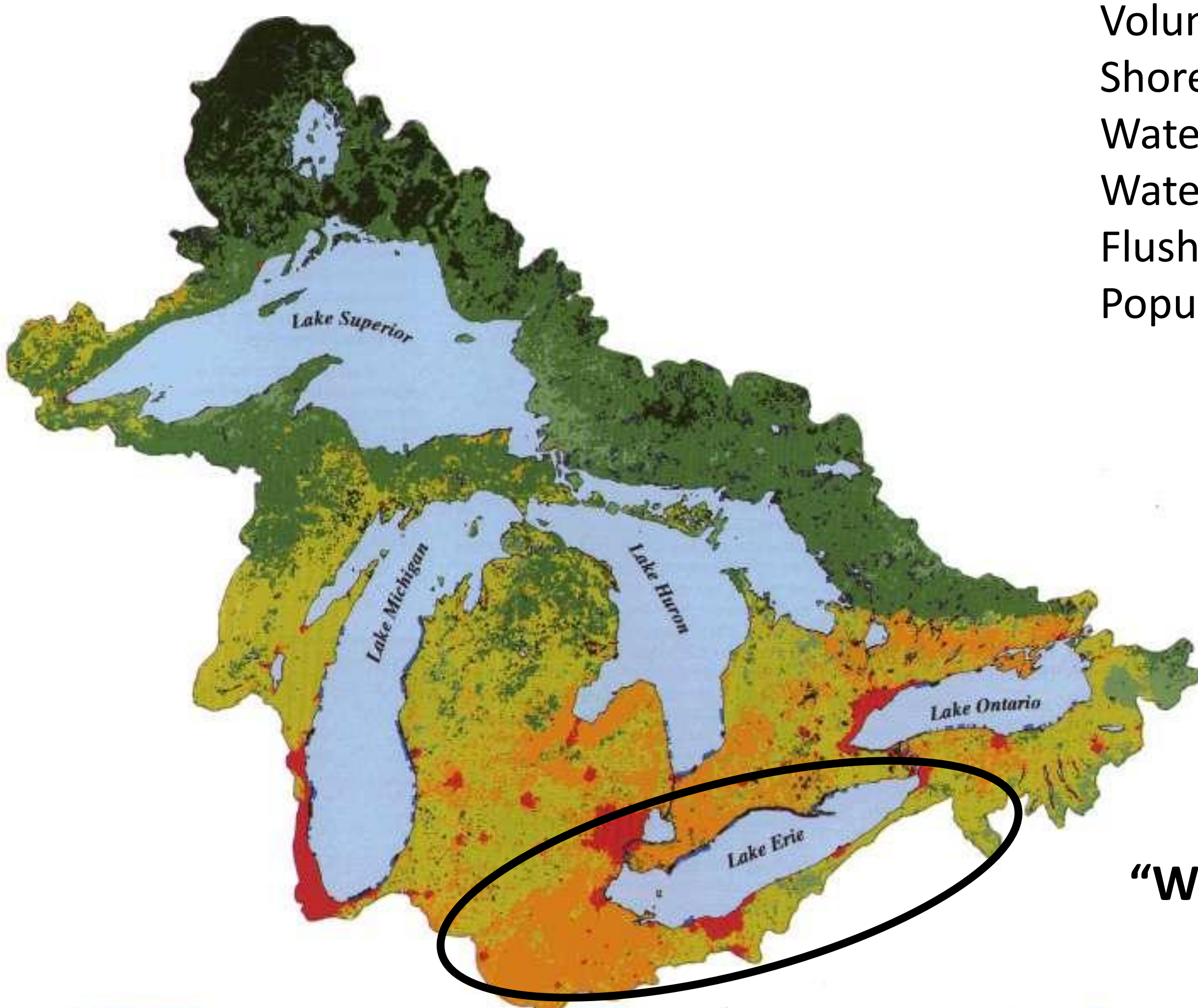
Three models



Lake Erie:

Southern most, warmest, and most productive Great Lake

Length: 241 miles
Breadth: 57 miles
Average Depth: 19 m
Maximum Depth: 64 m
Volume: 116 cubic miles
Shoreline Length: 871 miles
Water Surface Area: 9,910 square miles
Watershed: 30,140 square miles
Flushing Time: 2.6 years
Population: 10.5 million U.S.
1.9 million Canada



"Walleye Capital of the World"

What are

HABs?

(Harmful algal blooms)

Hypoxia?

(aka, the dead zone)

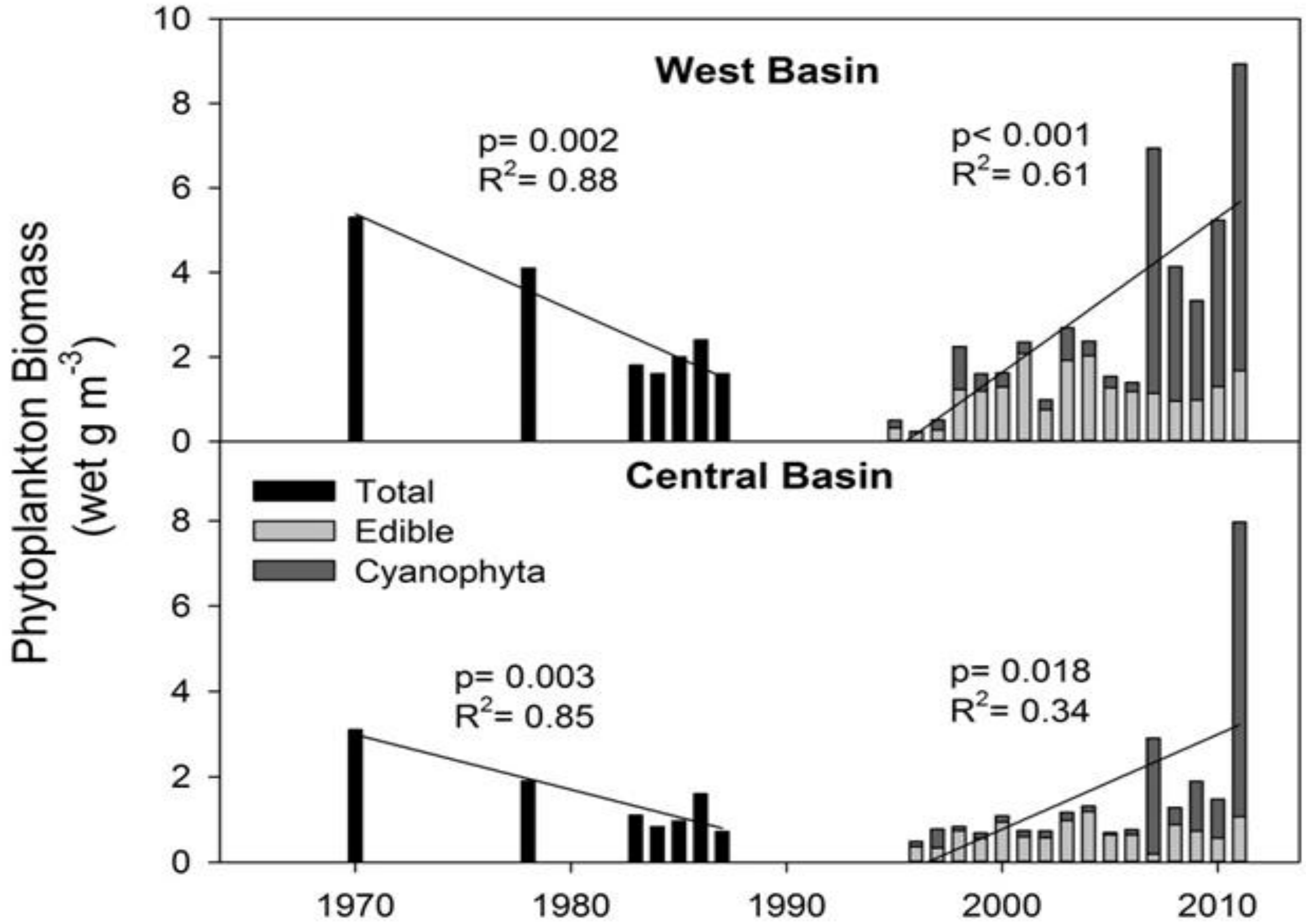
Fish?

(fun to watch, good to eat)

Massive 2011 Toxic Bloom

Western Basin Algal Booms

Decrease through the mid-1990s
Then a resurgence



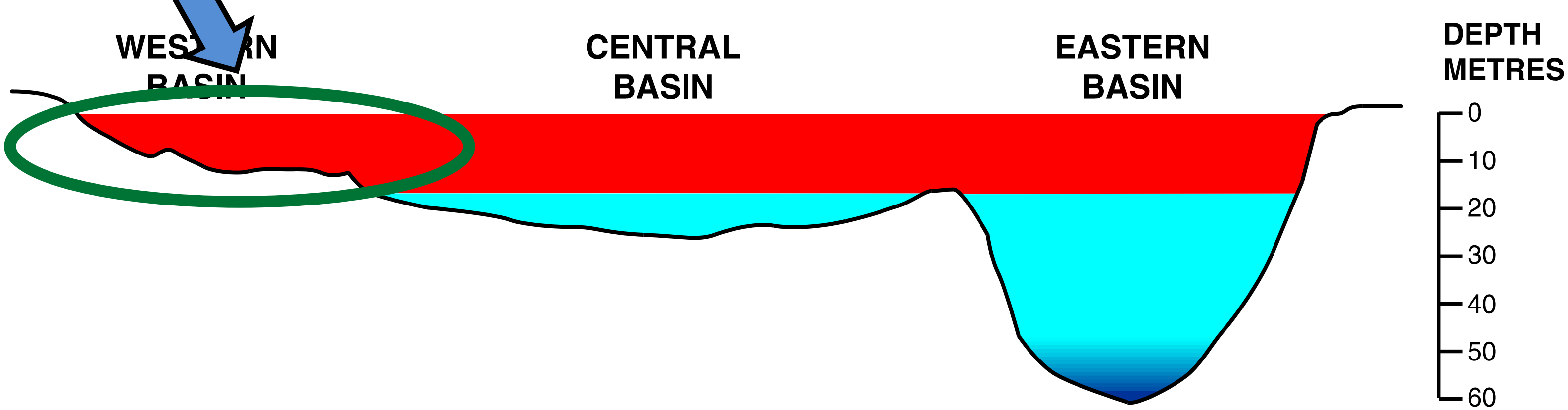
Scavia et al. (in press)

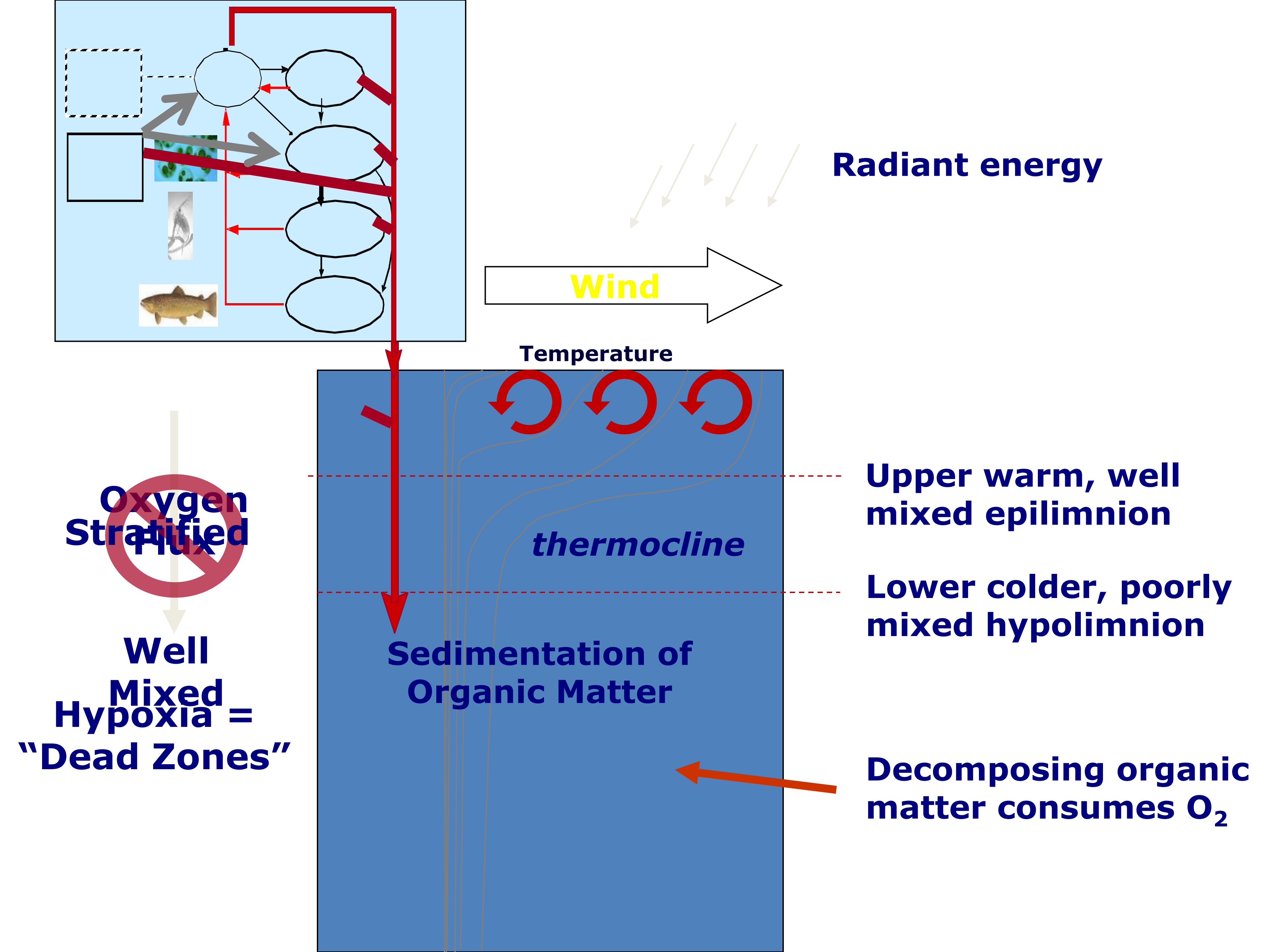
What Matters to Algal Blooms?

Air temperature, winds, length of season

Algal production and settling

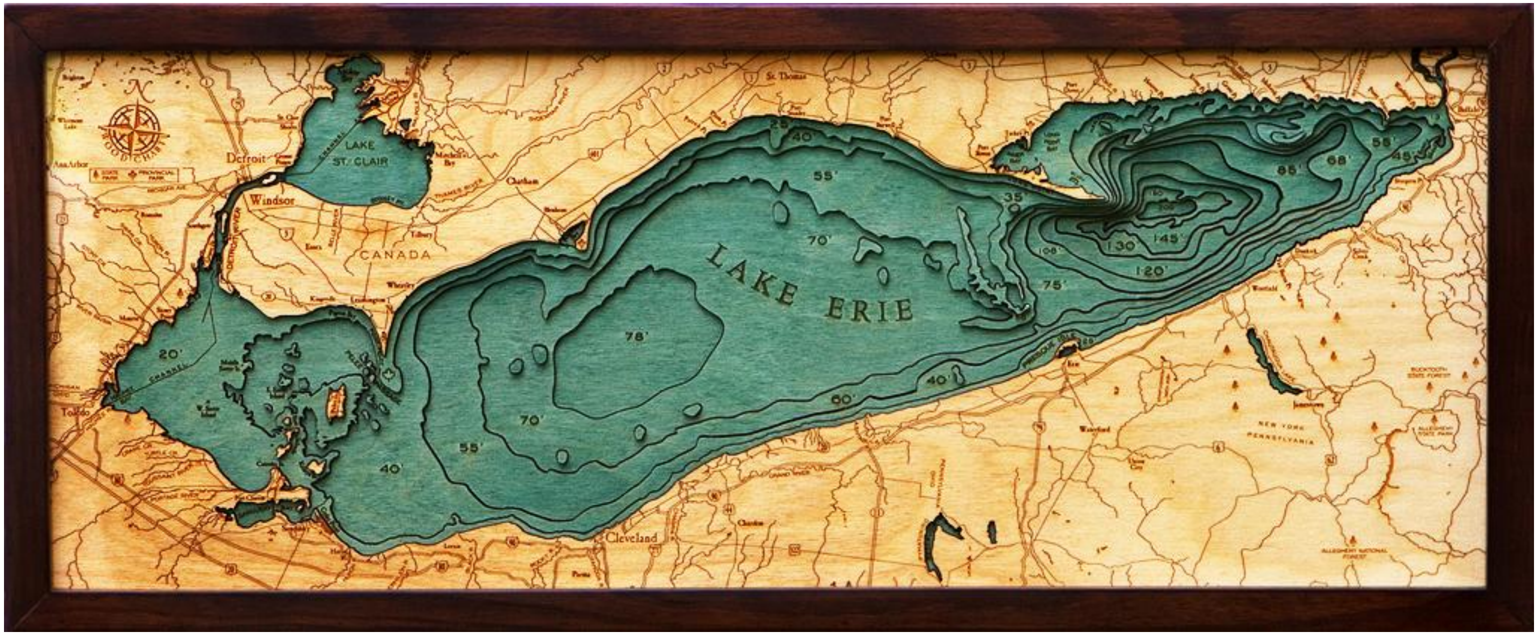
- **P supply**
- **Length of season**

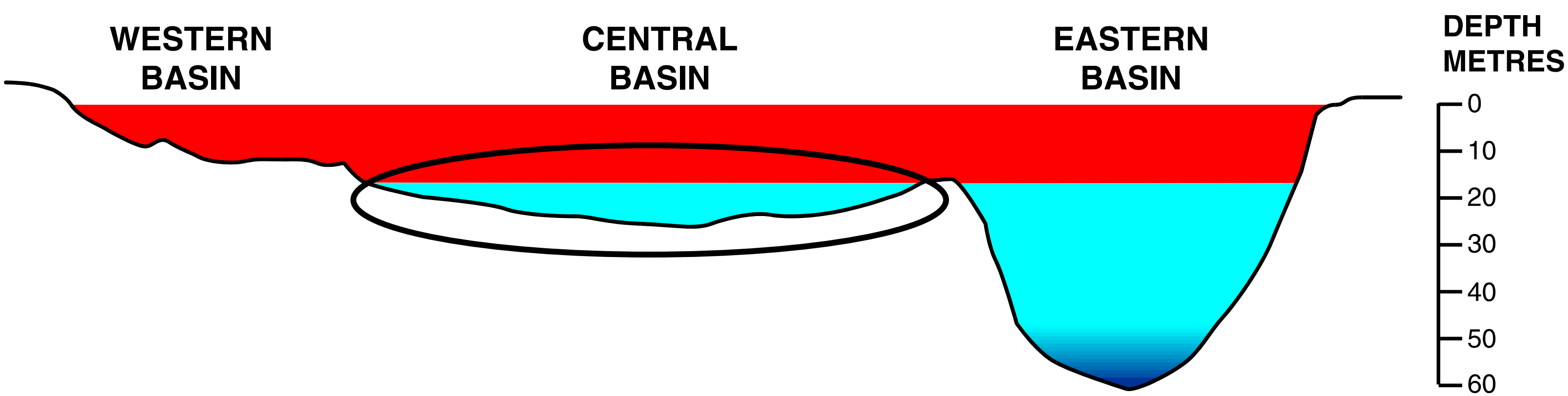




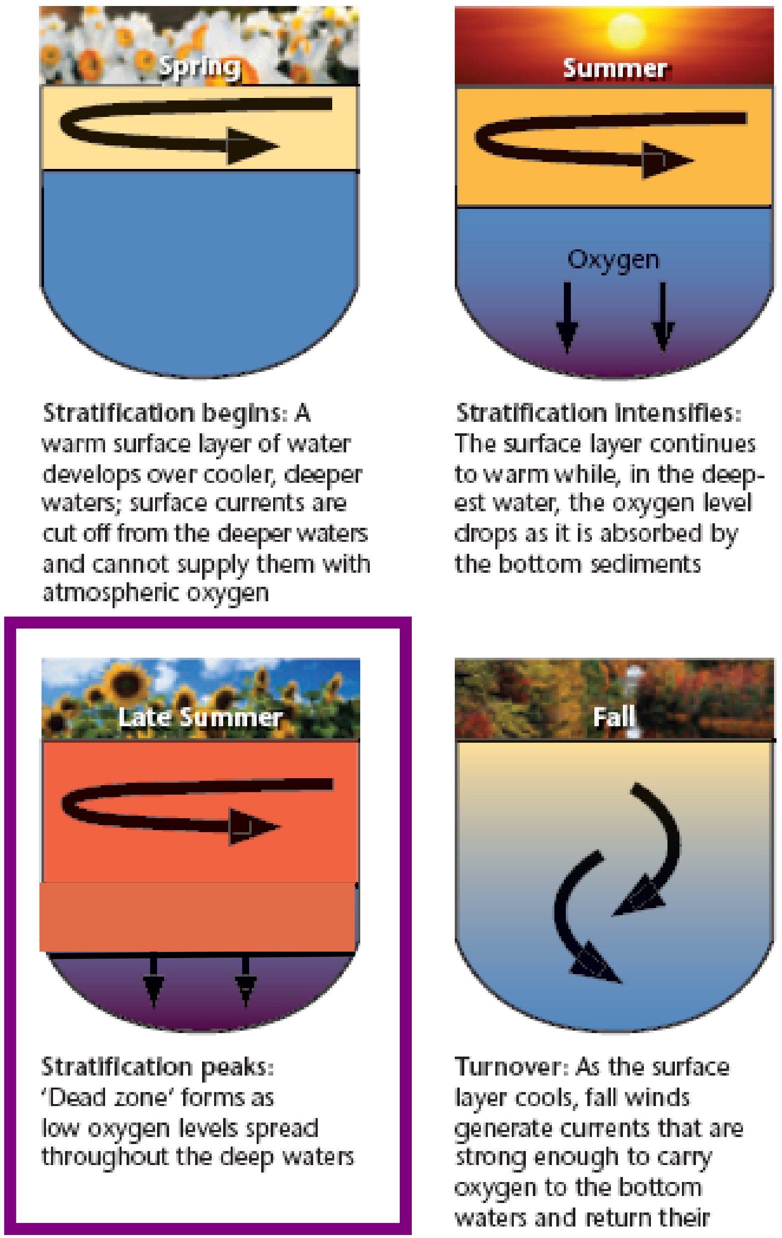
Radiant energy
Wind
Temperature
Upper warm, well mixed epilimnion
thermocline
Lower colder, poorly mixed hypolimnion
Sedimentation of Organic Matter
Decomposing organic matter consumes O_2
Oxygen Flux
Stratified
Well Mixed
Hypoxia = “Dead Zones”

Special Physical Characteristics





Thinner Bottom Layer?



=> Less O_2 Available

What Matters to Hypoxia?

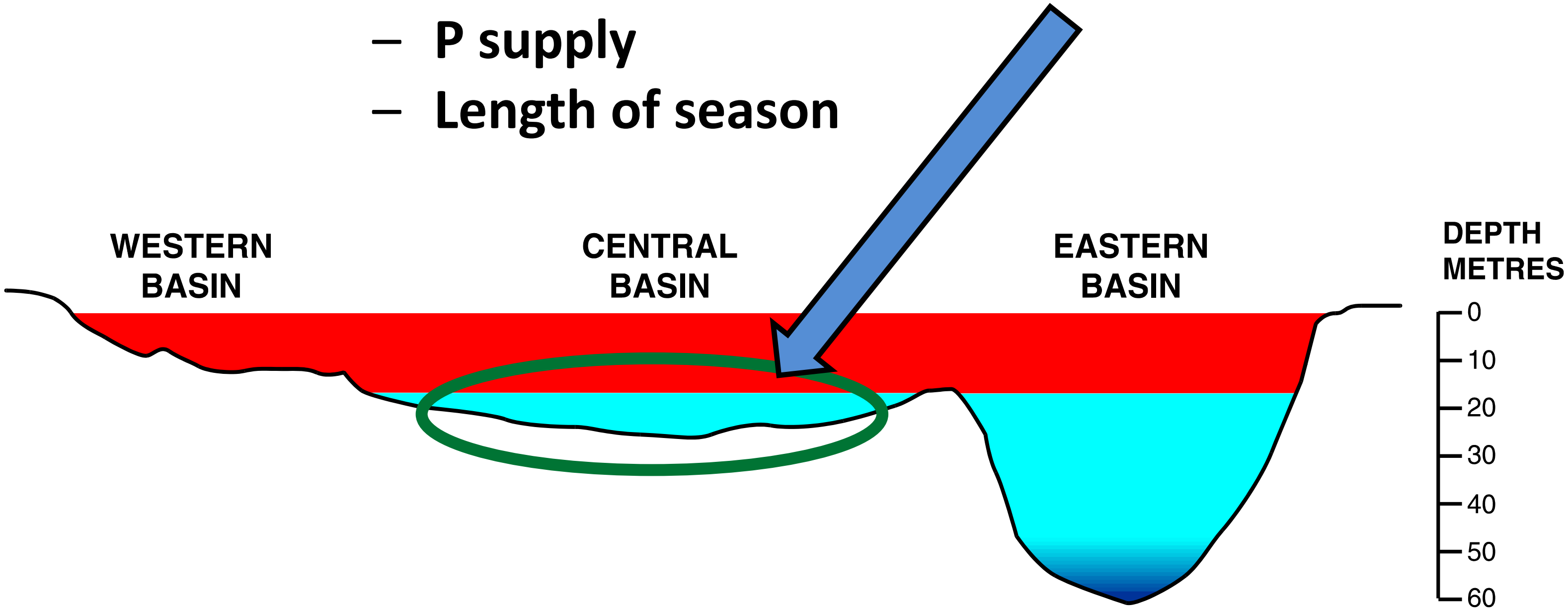
Thickness of Central Basin Bottom Layer

Air temperature, winds, length of season

Organic Matter Flux to the Bottom

Algal production and settling

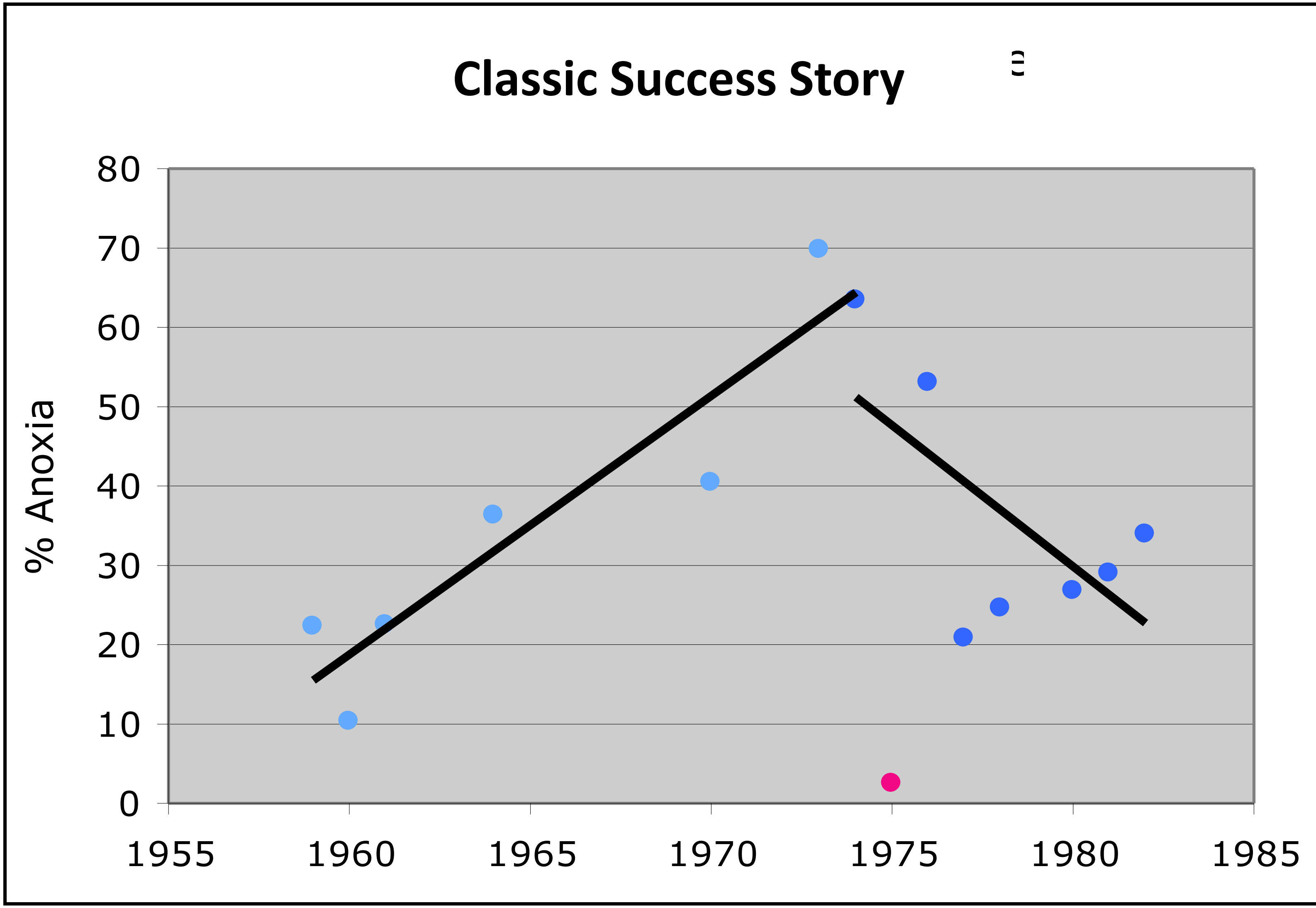
- P supply
- Length of season



Central Basin Anoxia (no oxygen)

Increased through 1970s (phosphorus loading)

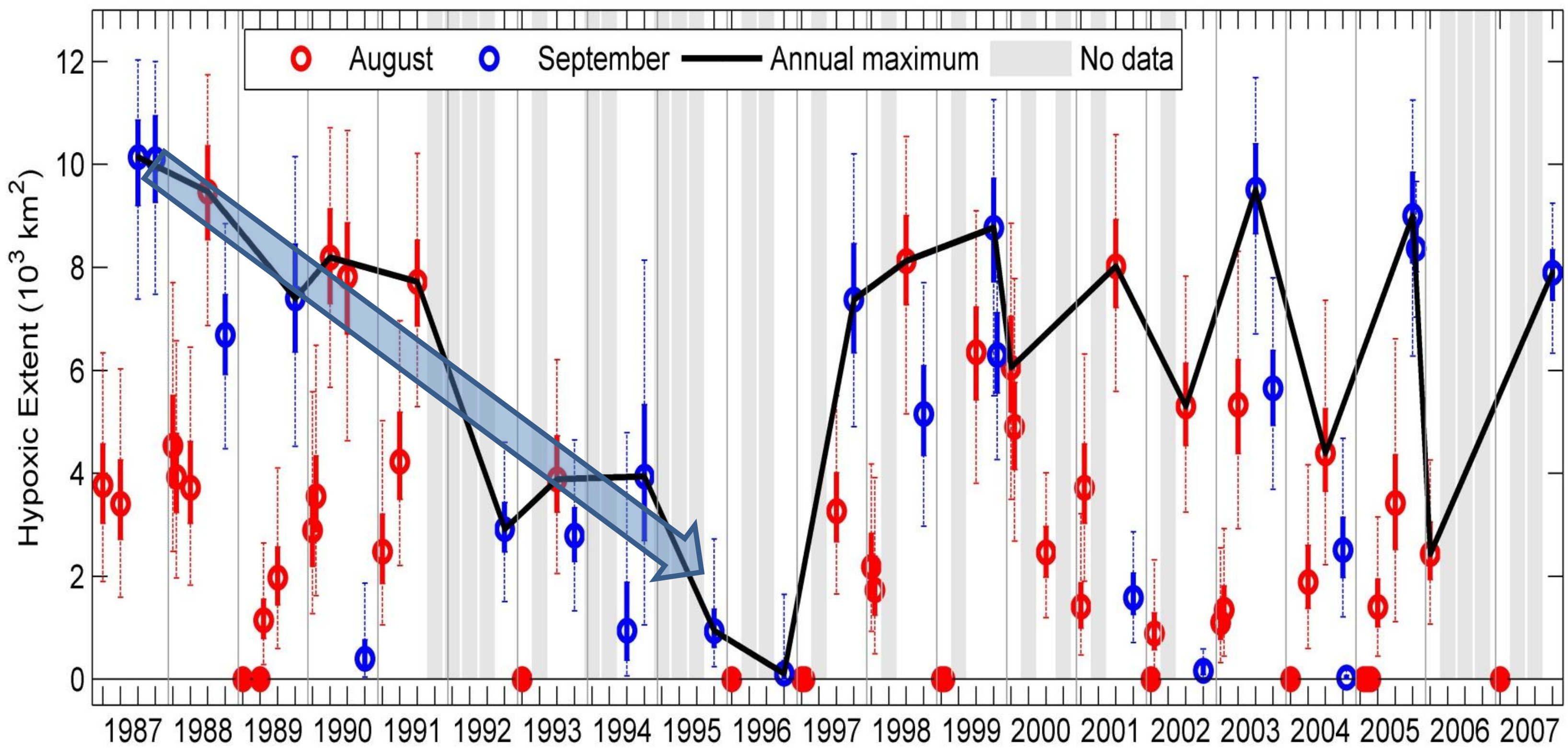
Decreased following GLWQA-based clean-up



Central Basin Hypoxia (DO< 2 mg/l)

Downward trend continued through the mid-1990s

Then a resurgence



Zhou et al. 2012

The Team

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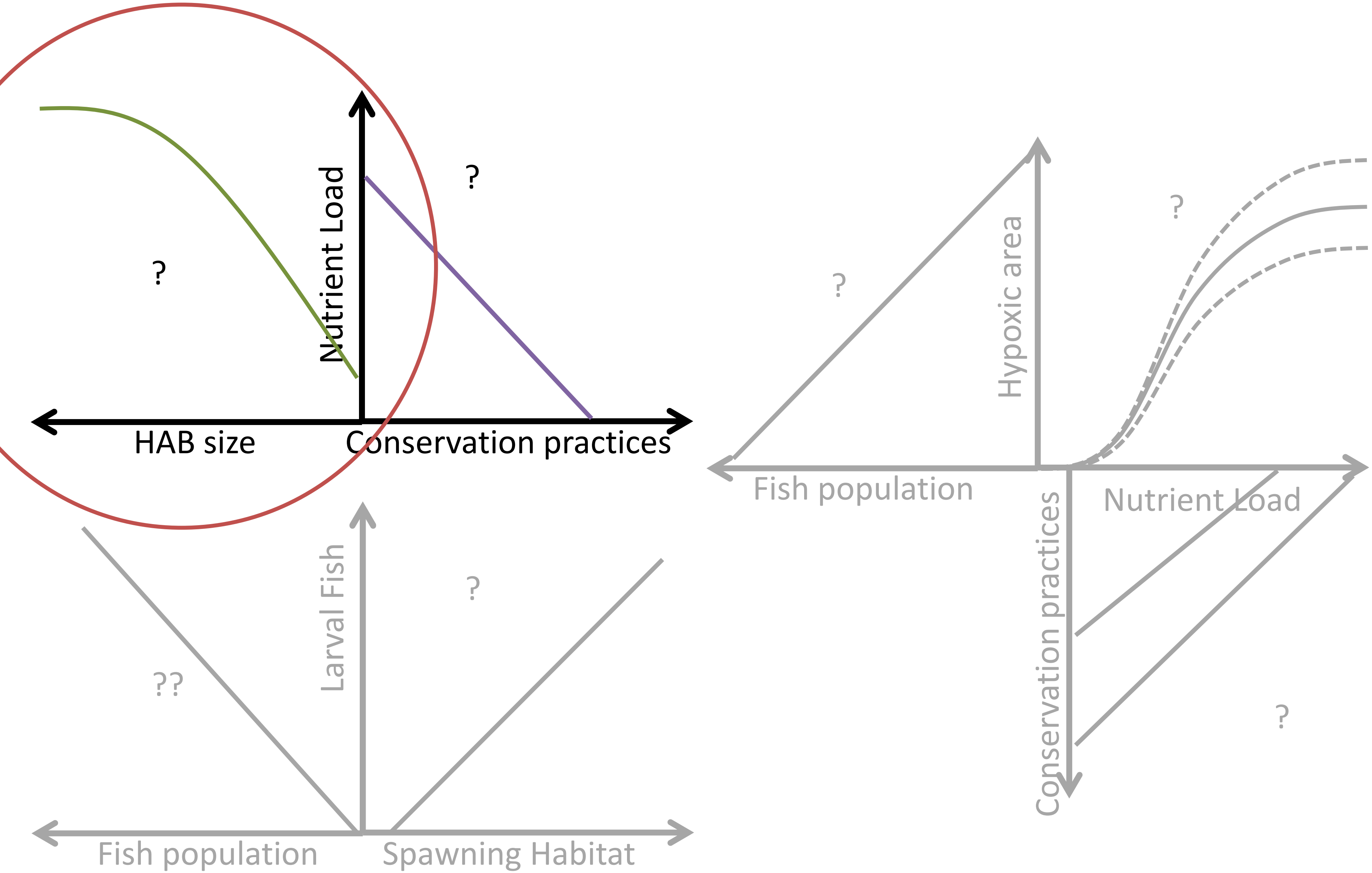
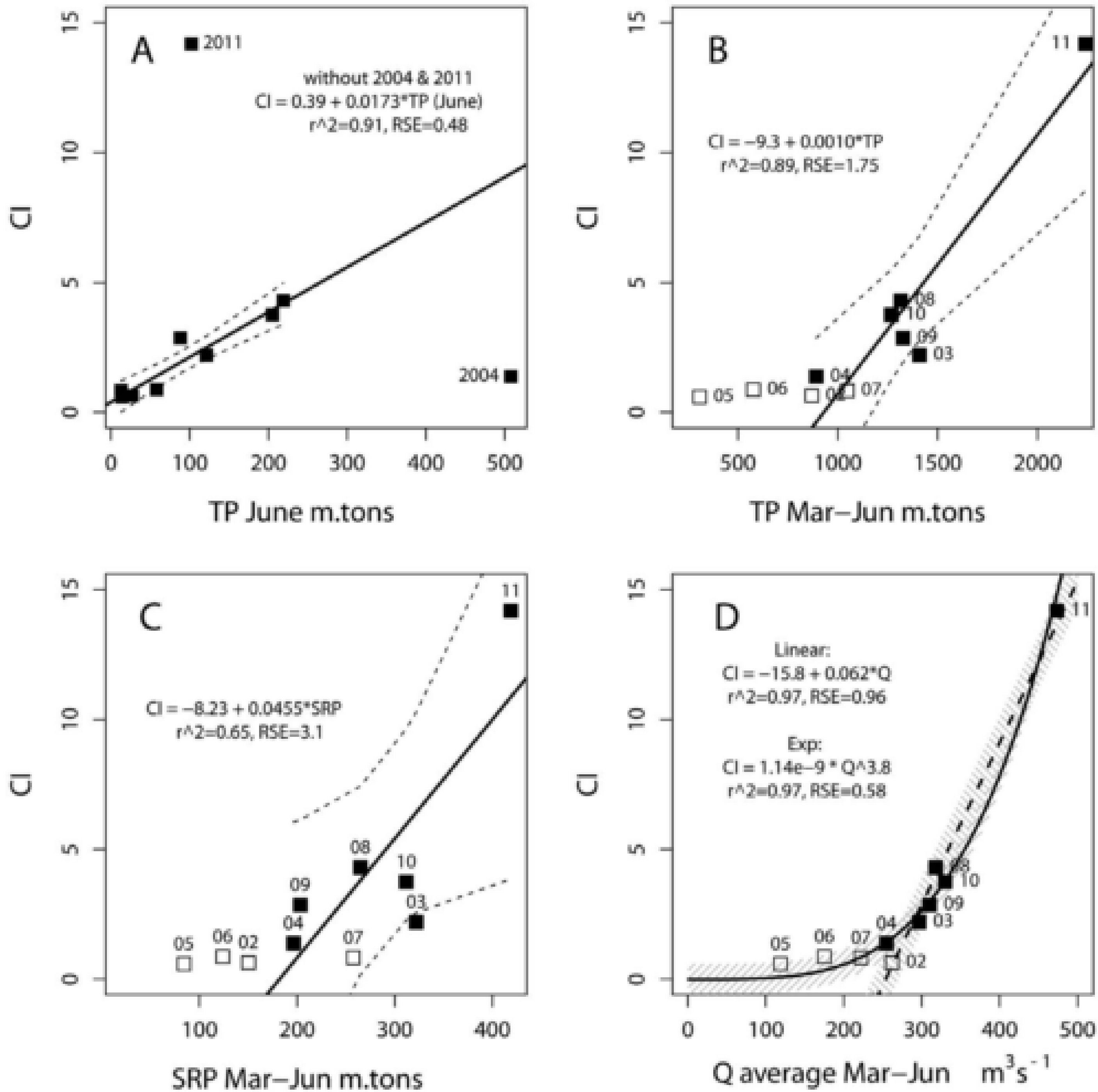
Physical Scientists, Ecologists and Chemists, Physical and Ecological Modellers, Engineers, Social Scientists, Practitioners

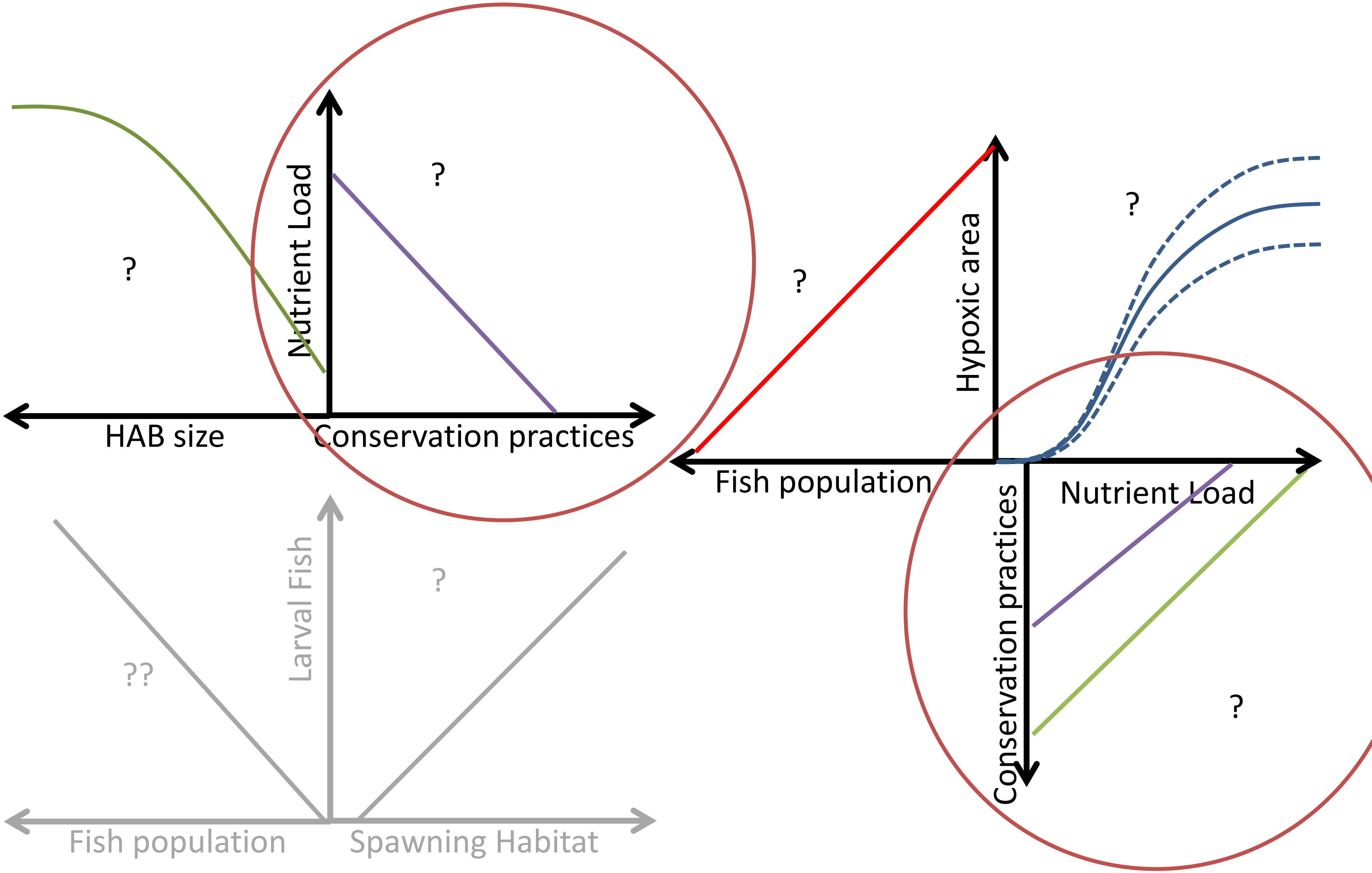
Three models





Stumpf et al. 2012

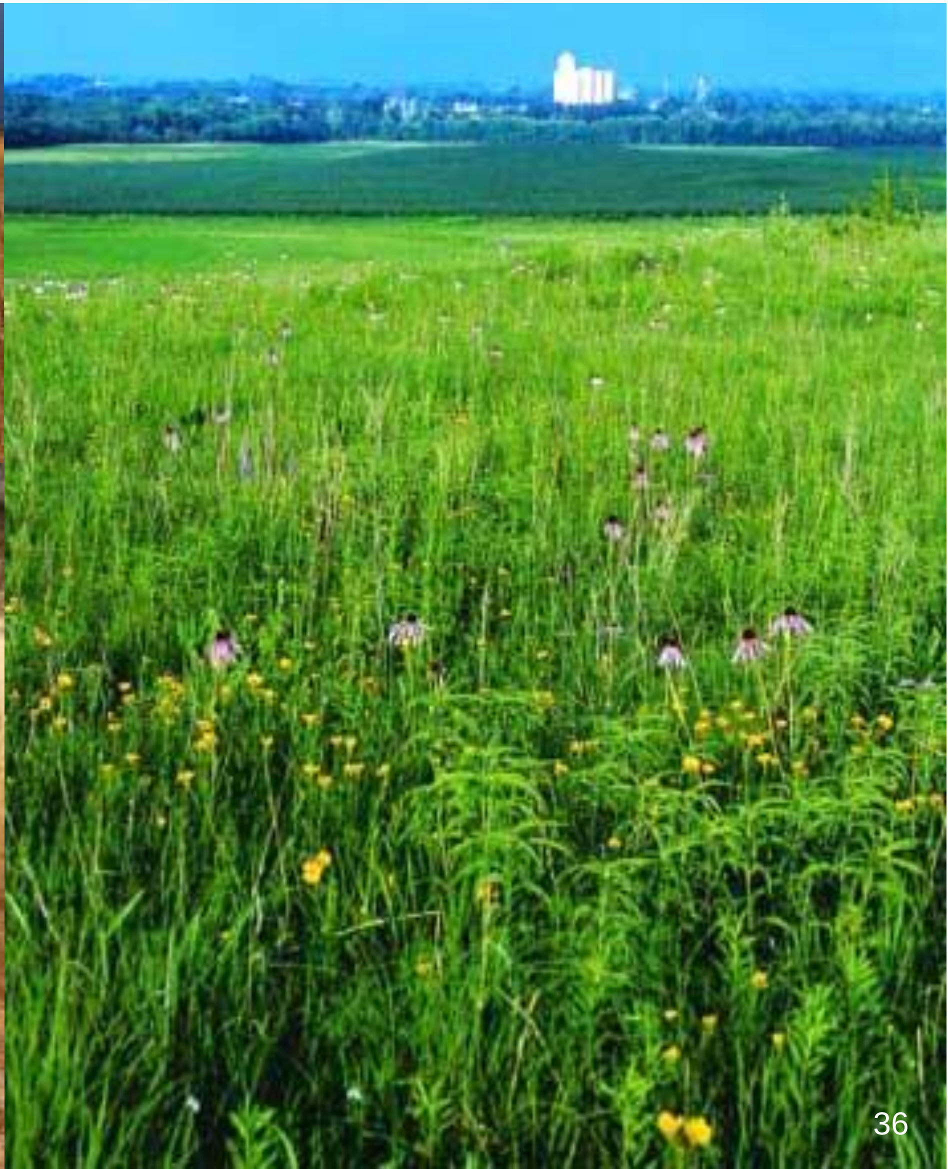
Three models



Conservation practices
Non-structural

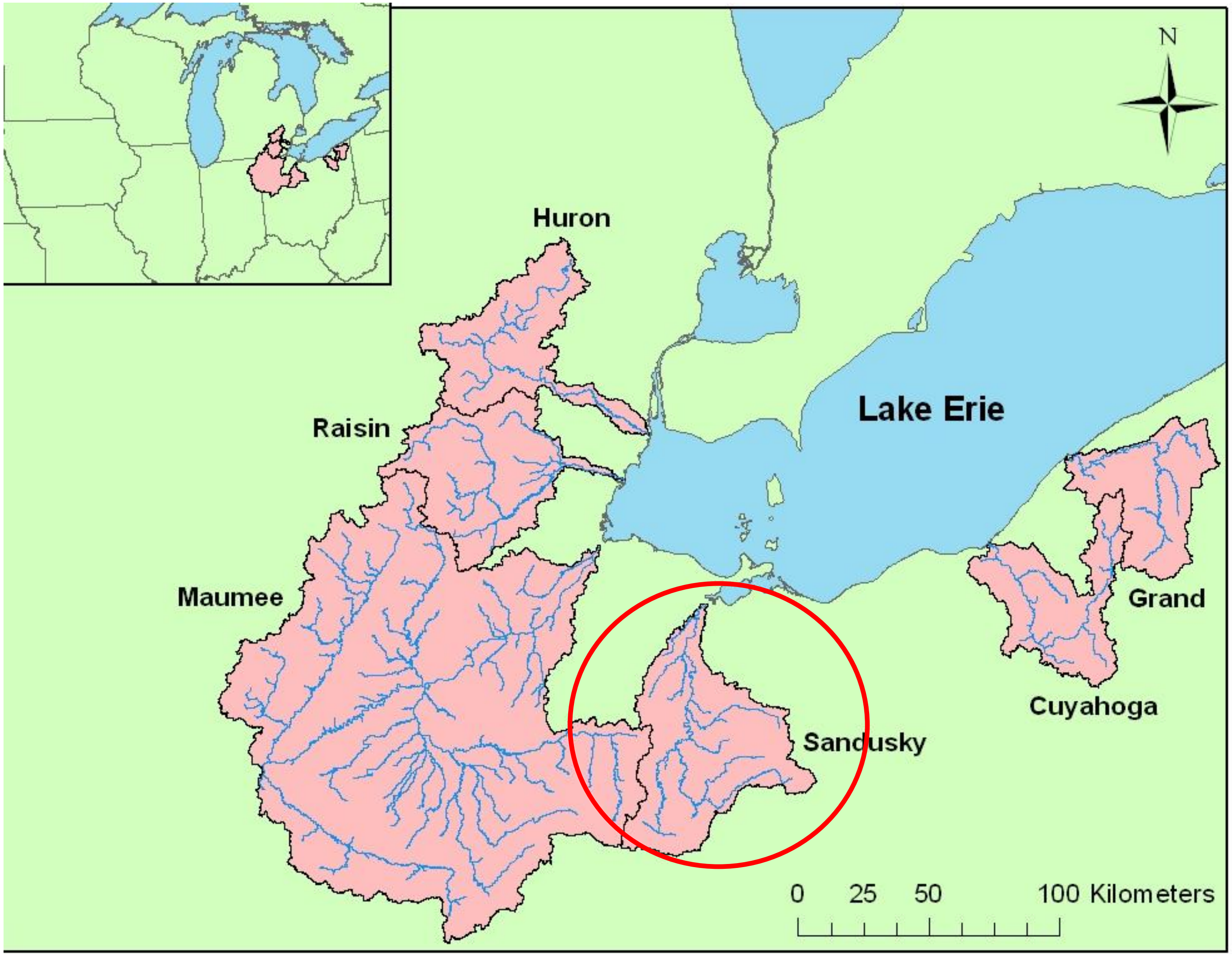
Conservation practices
Structural

Conservation practices
Land retirement programs



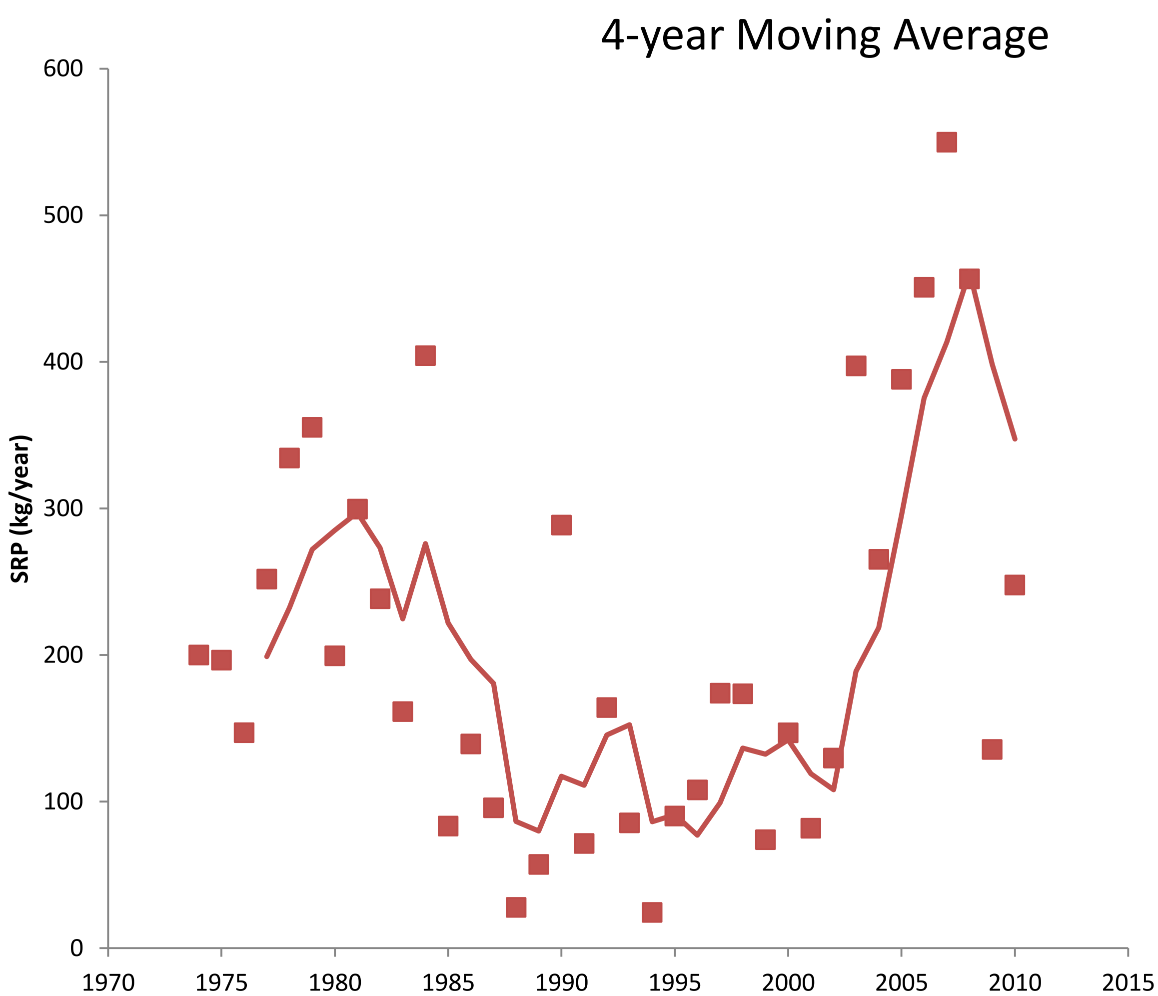
Conservation practices
Nutrient Management Plans

High-resolution SWAT model the Sandusky Watershed



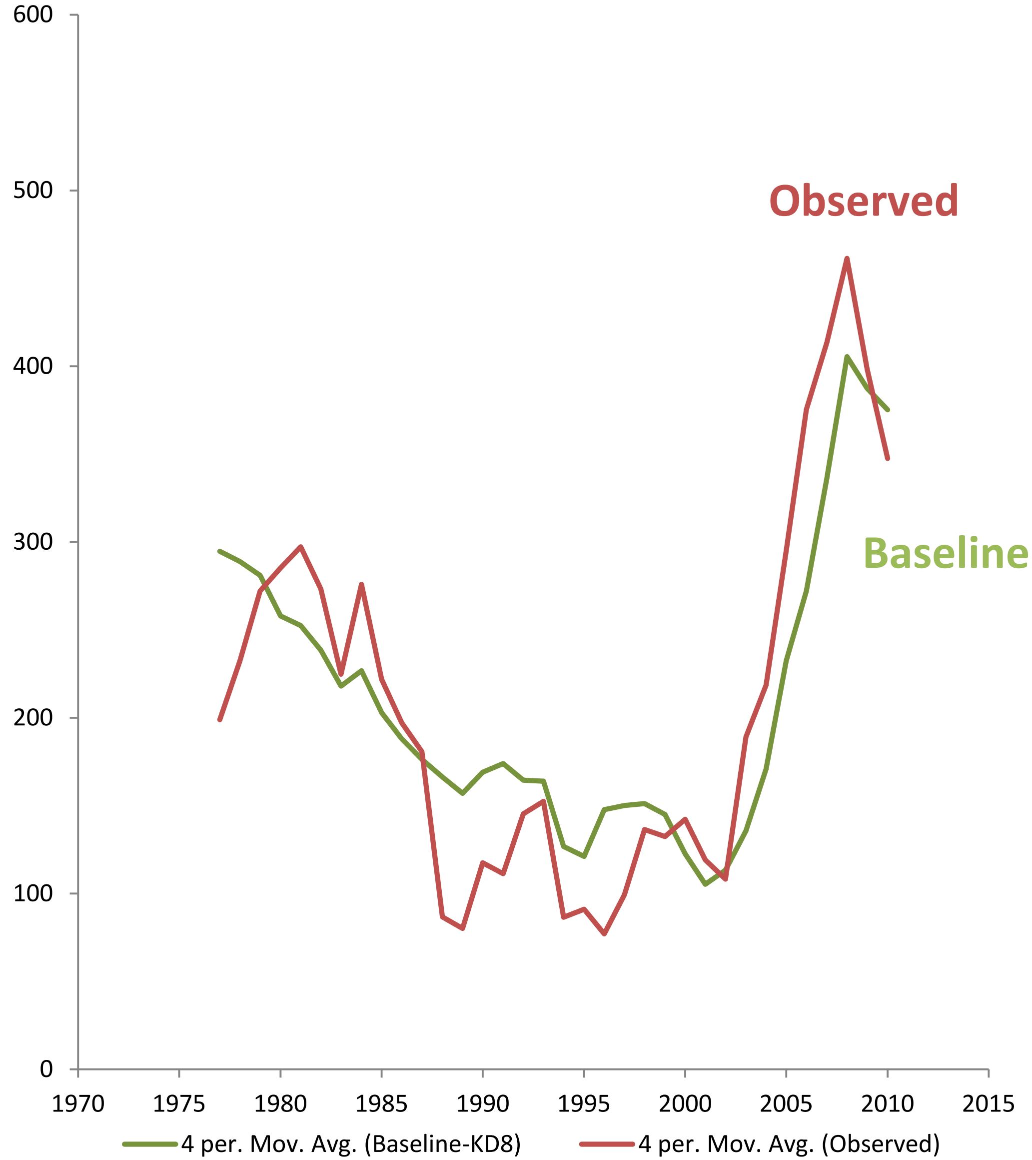
I. Daloglu

Observed DRP Load



P. Richards

Calibrated and validated with observed Sandusky DRP loads

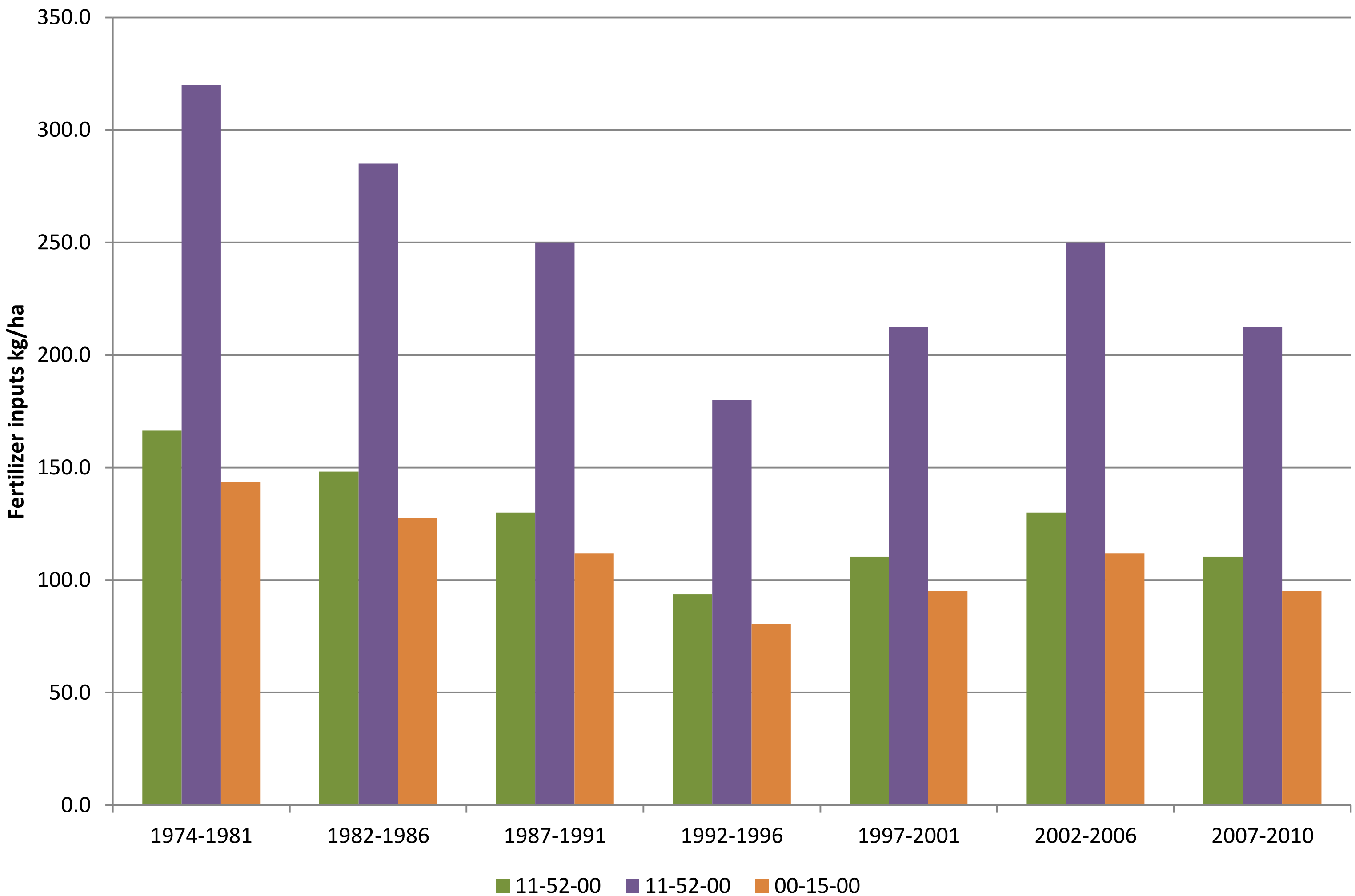


Baseline

Representative :

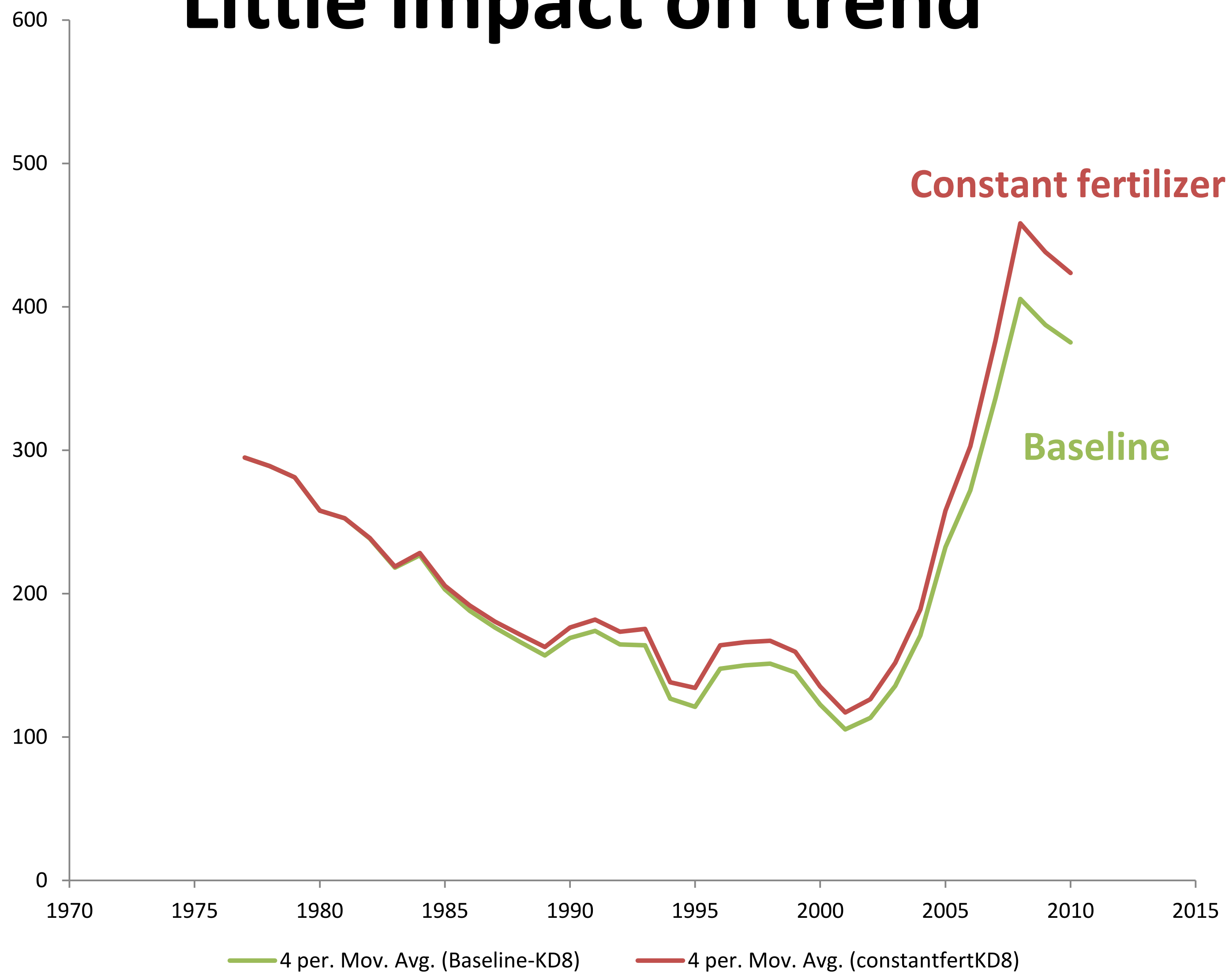
- **Tillage practices**
- **Fertilizer inputs**
- **Crop choices**
- **Fertilizer timing**
- **Soil P accumulation in topsoil**

How about fertilizer use trends?

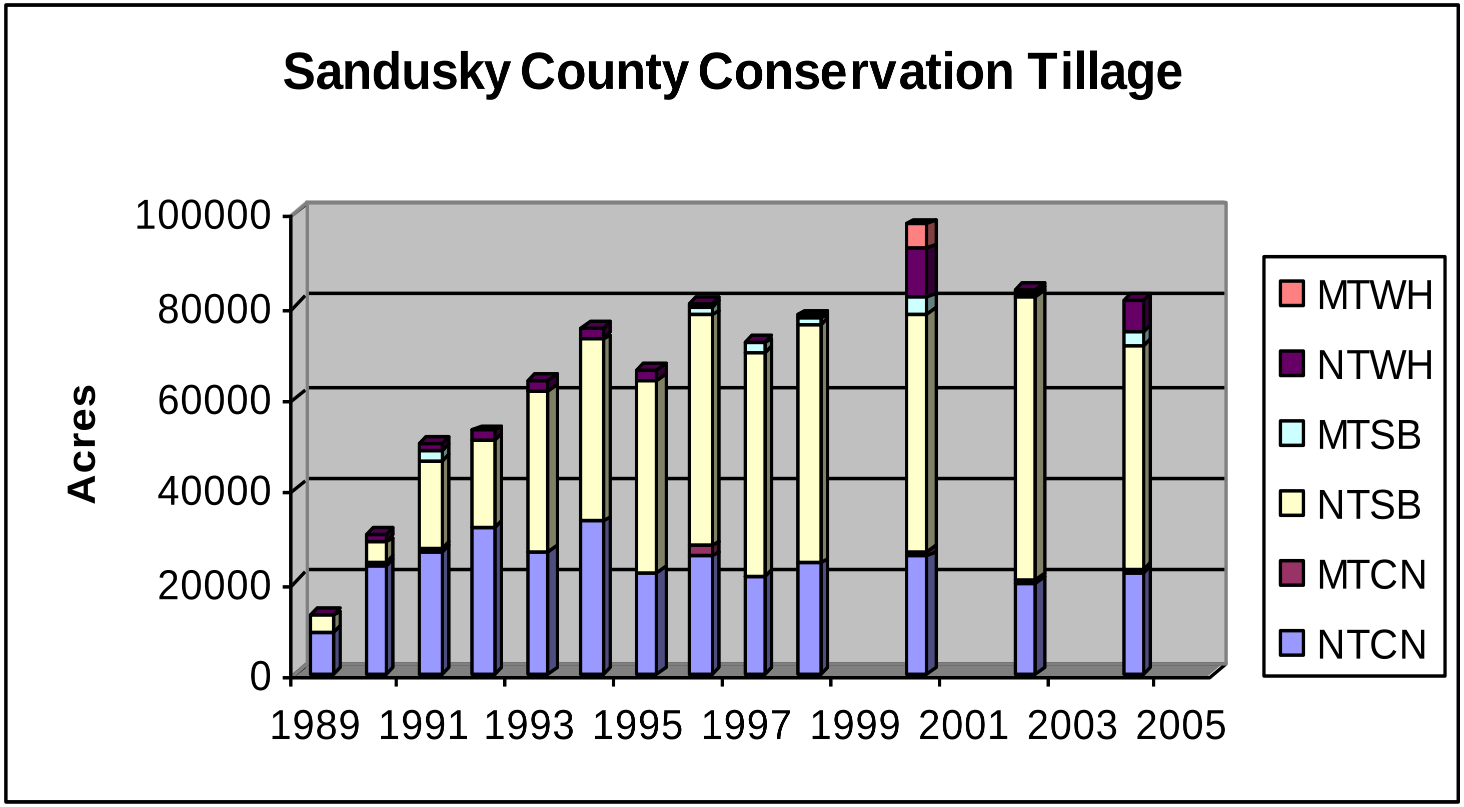


Han and Allan 2010

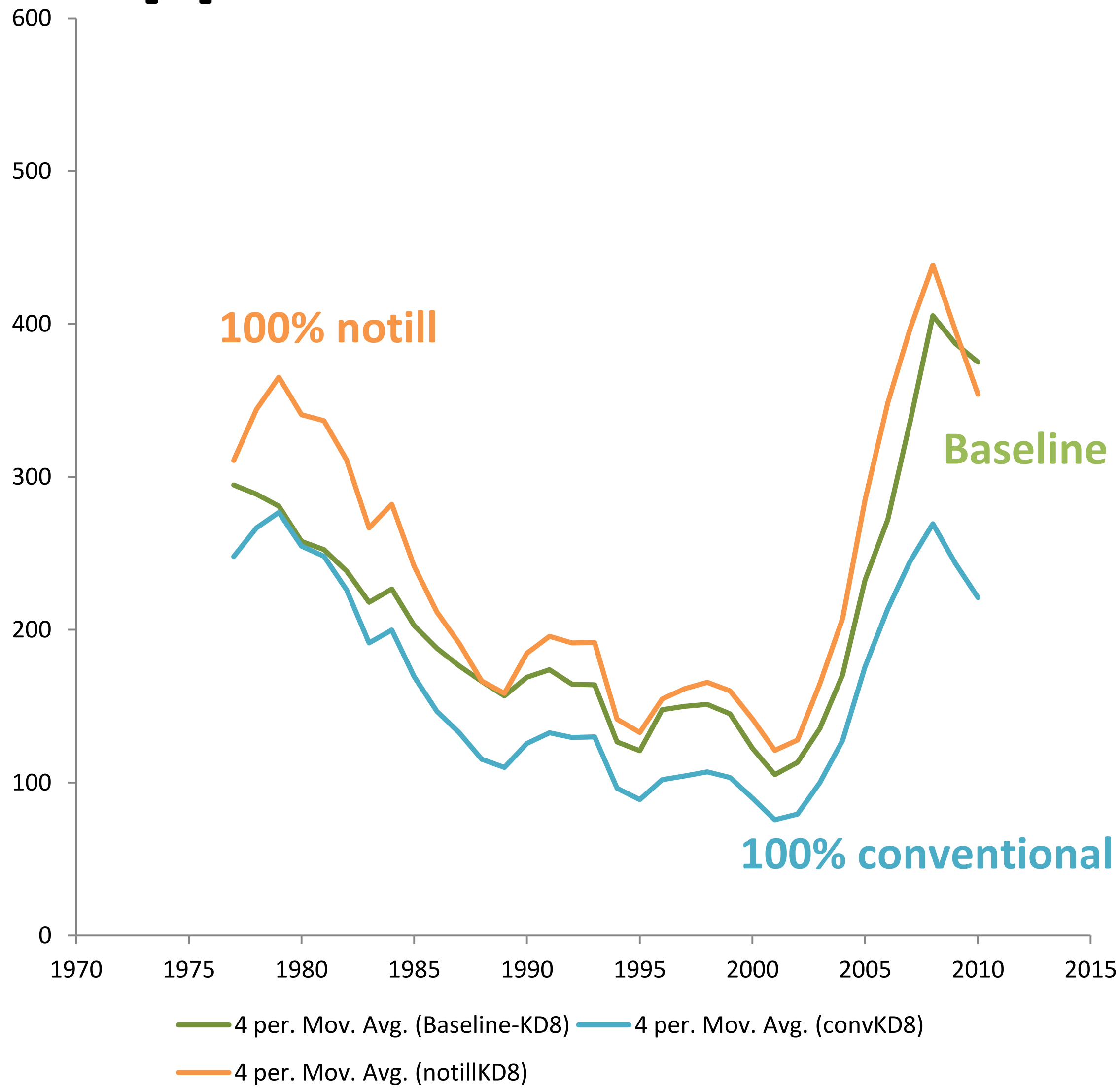
Fertilizer application rate scenario: Little impact on trend



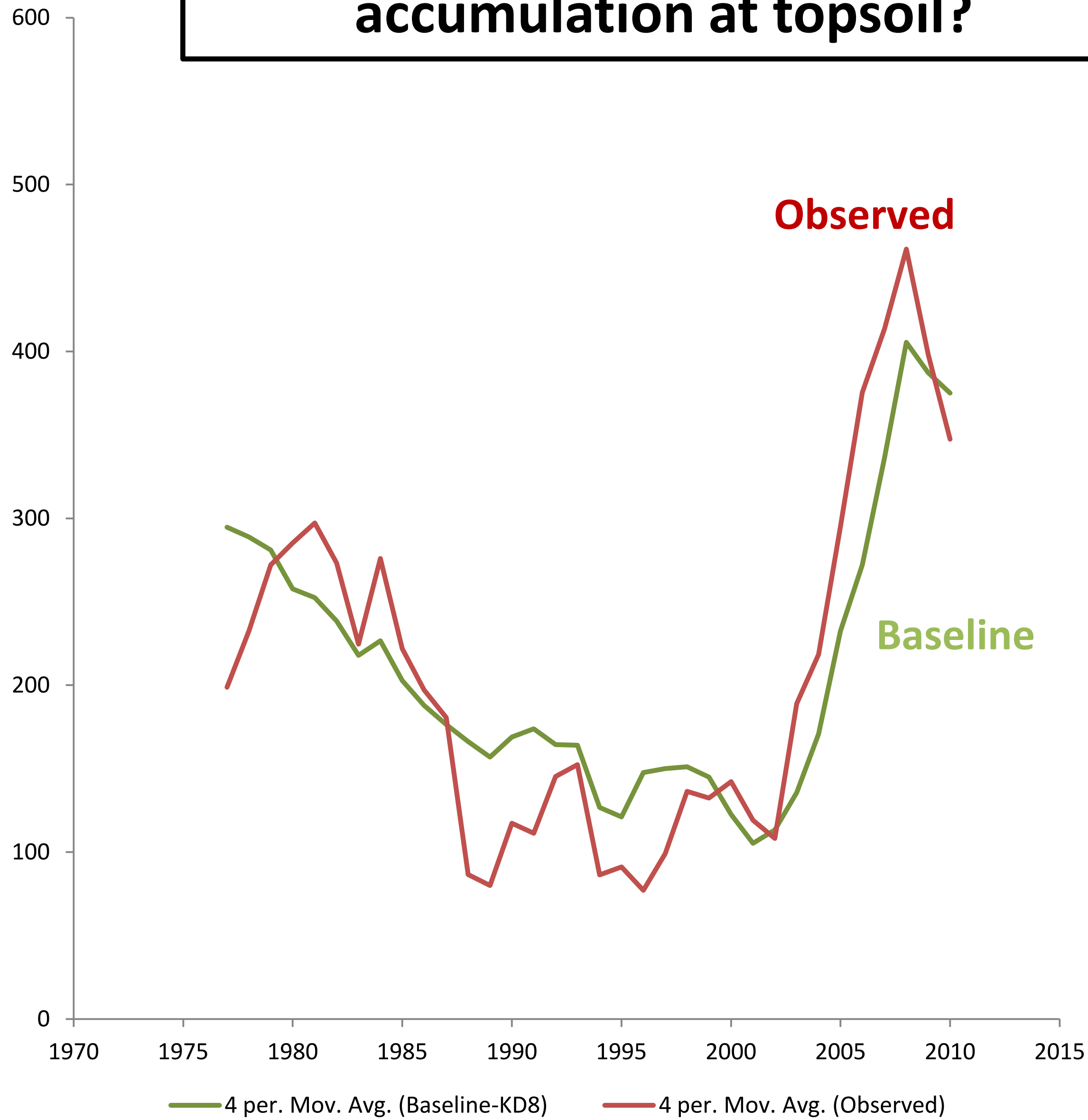
Tillage practices scenario: Increased conservation tillage



Tillage practices scenario: Appears to have some impact



Is this because of the P accumulation at topsoil?



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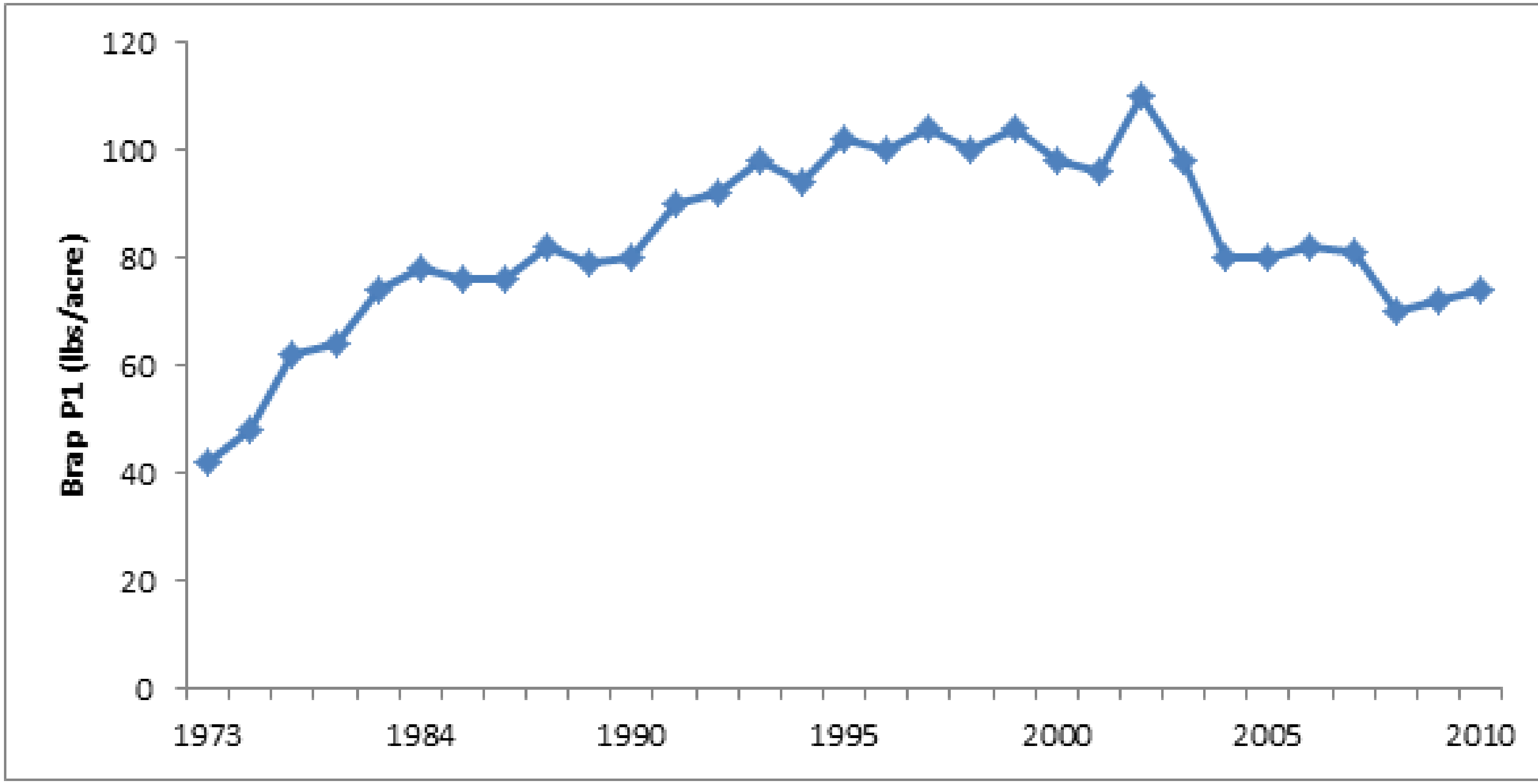


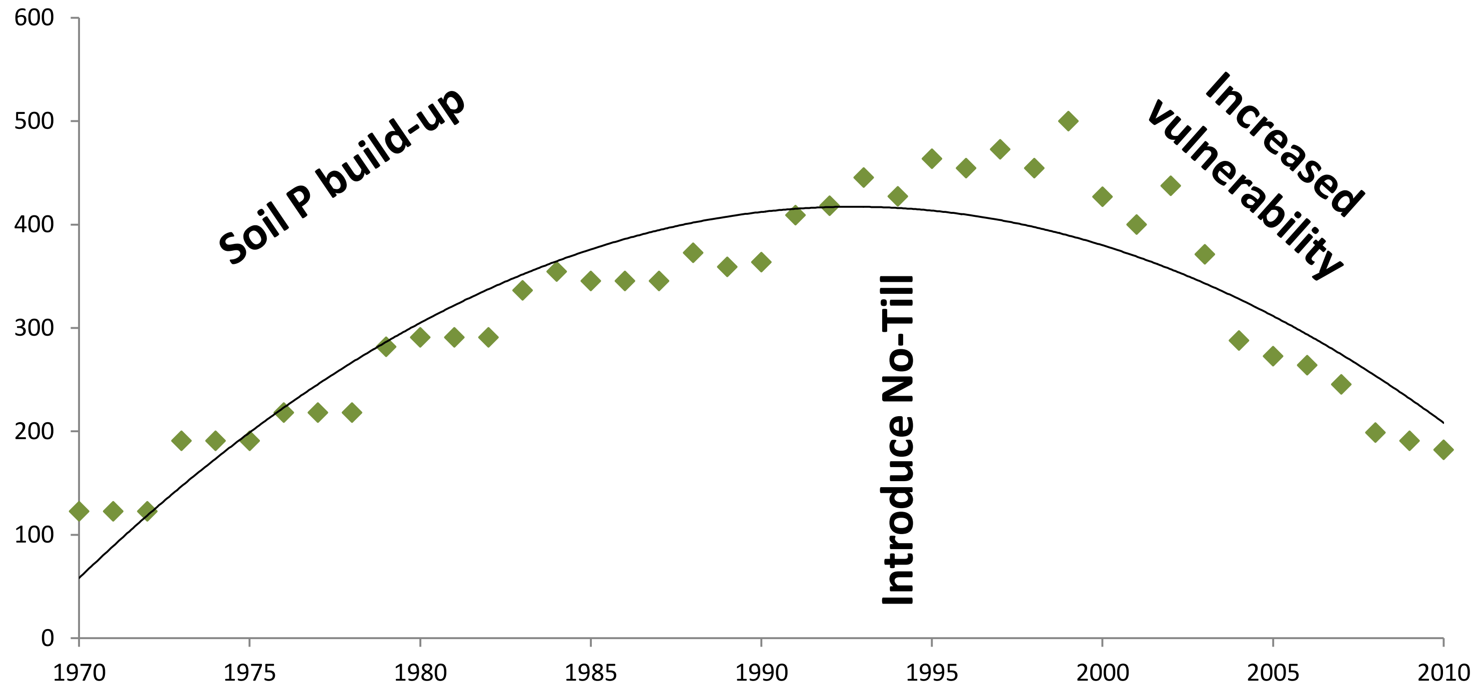
<u>Surface application</u> of P fertilizer and manure

Fertilizer application exceeding crop needs

Adoption of conservation tillage

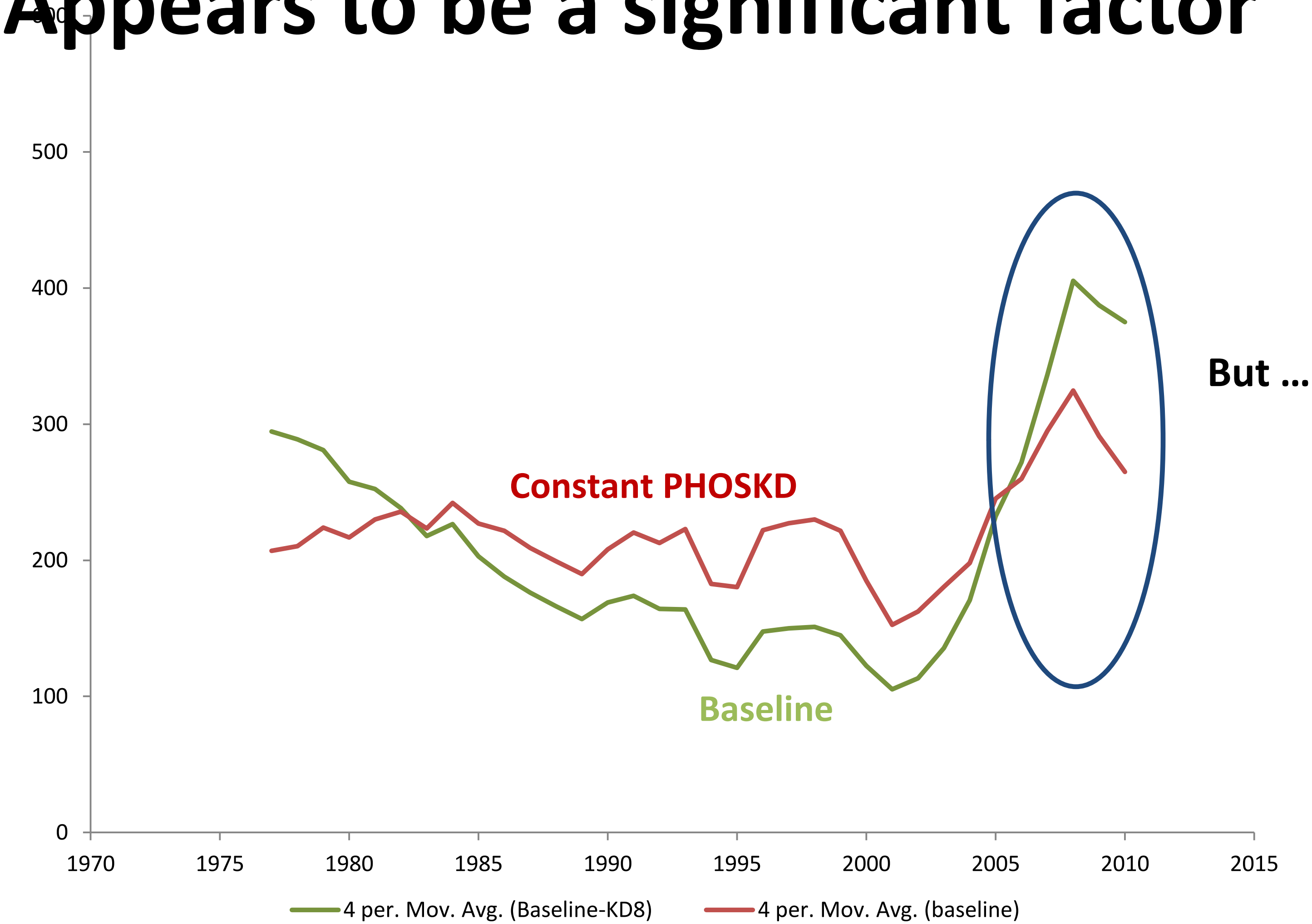
Soil stratification

Modified topsoil SRP: runoff concentration ratio in the SWAT model

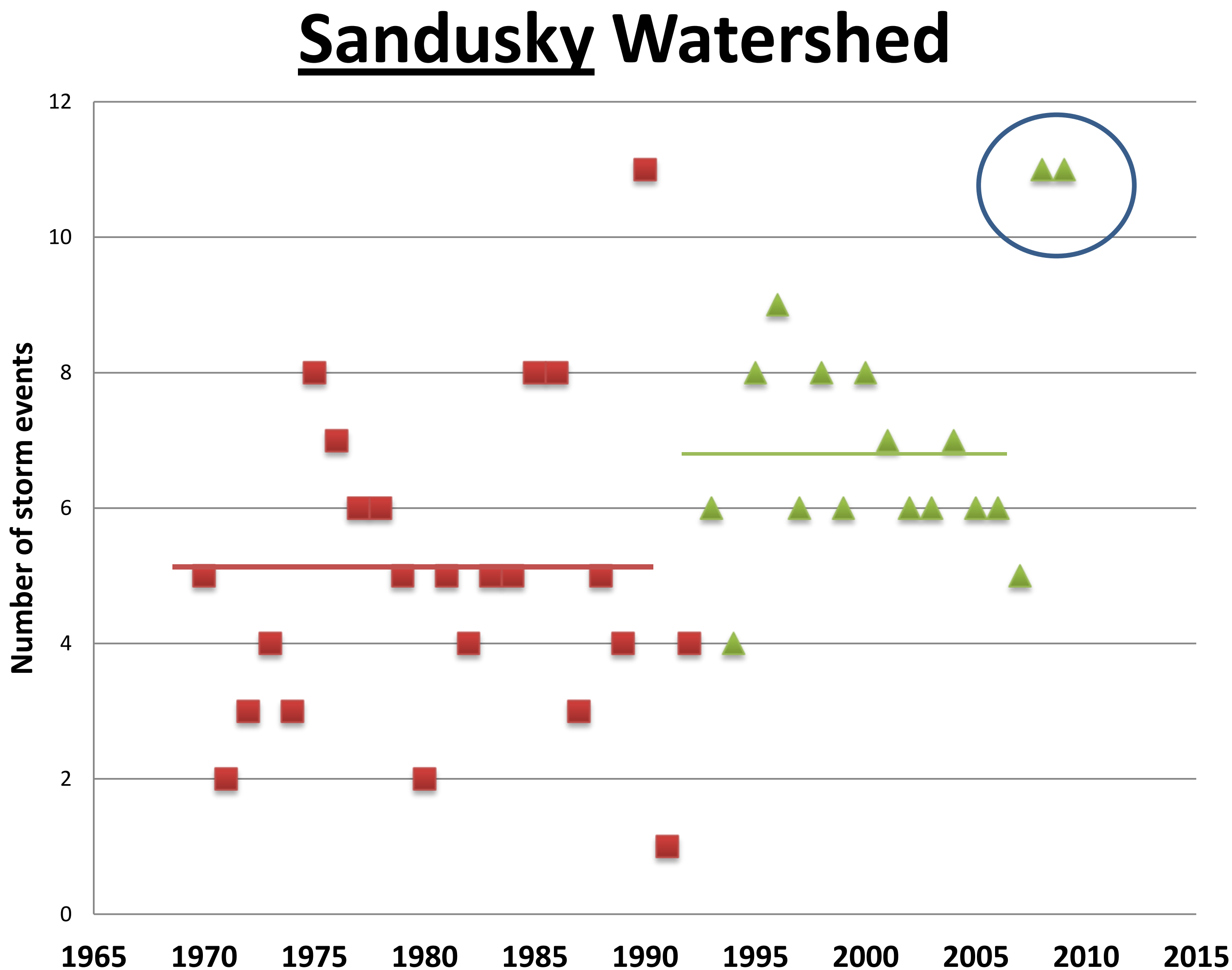


Higher values allow phosphorus to accumulate at topsoil
Lower values allow more P runoff/vulnerability

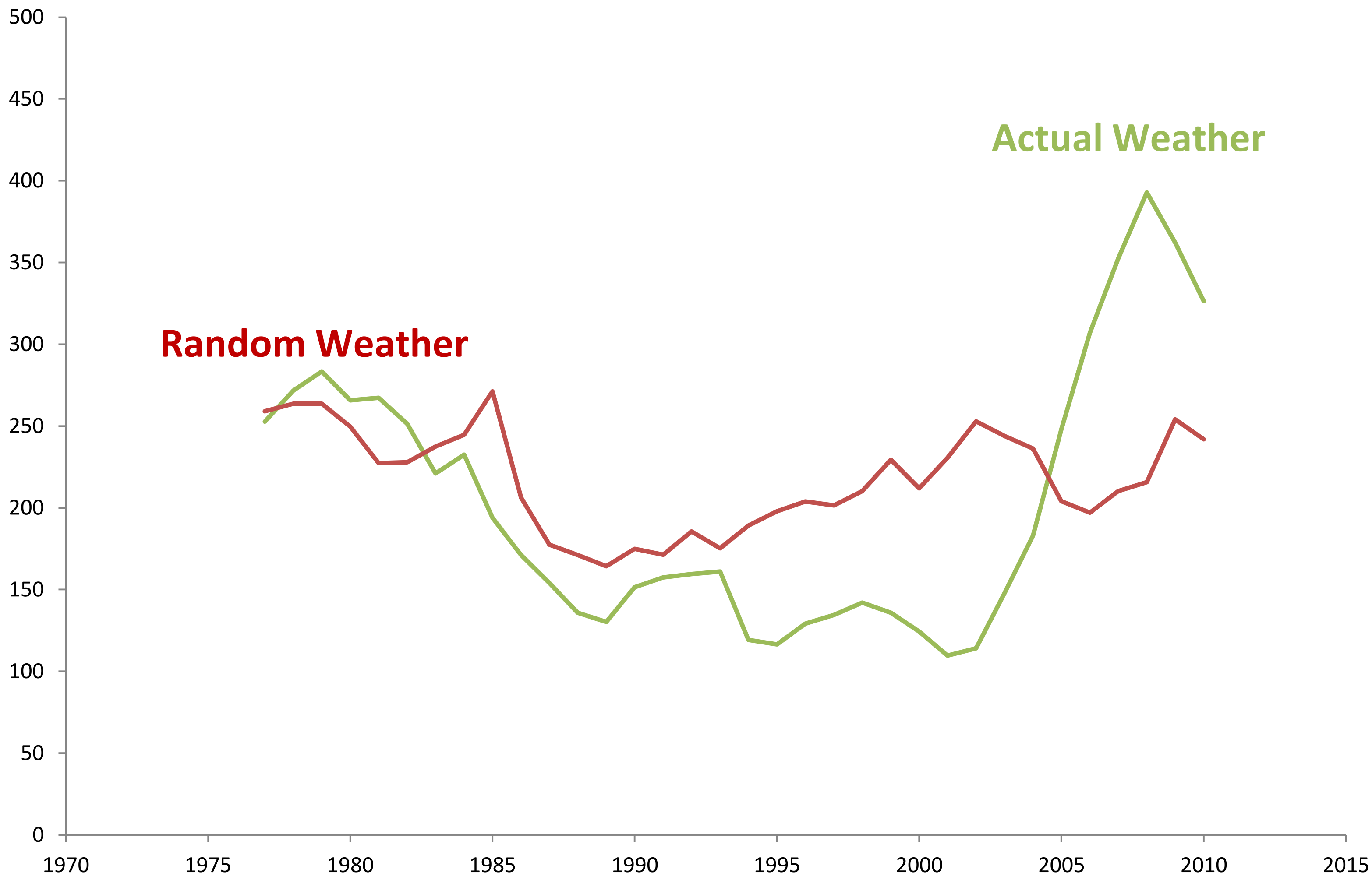
Simulated SRP Load
Appears to be a significant factor



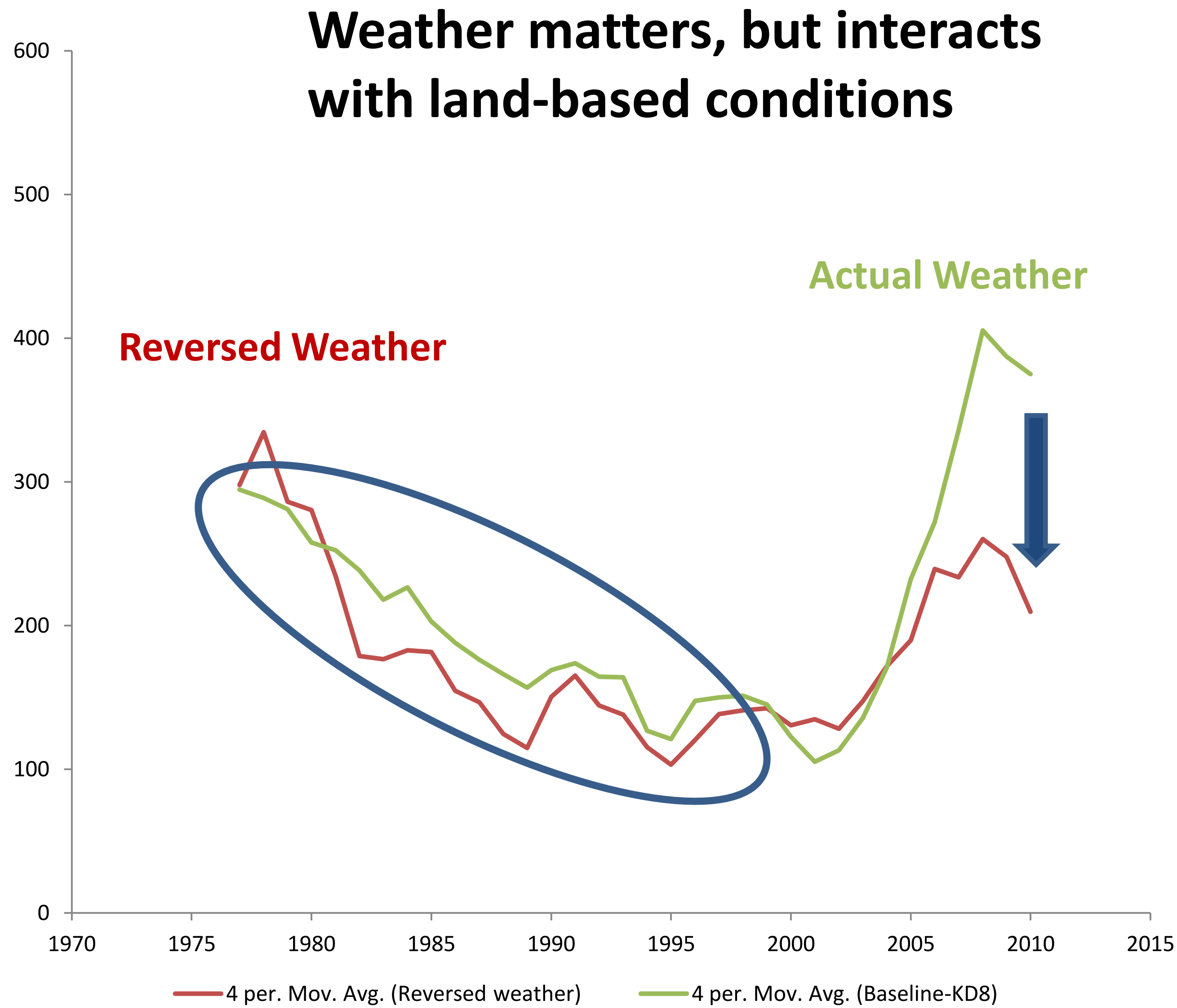
Lake Erie Extreme Precipitation



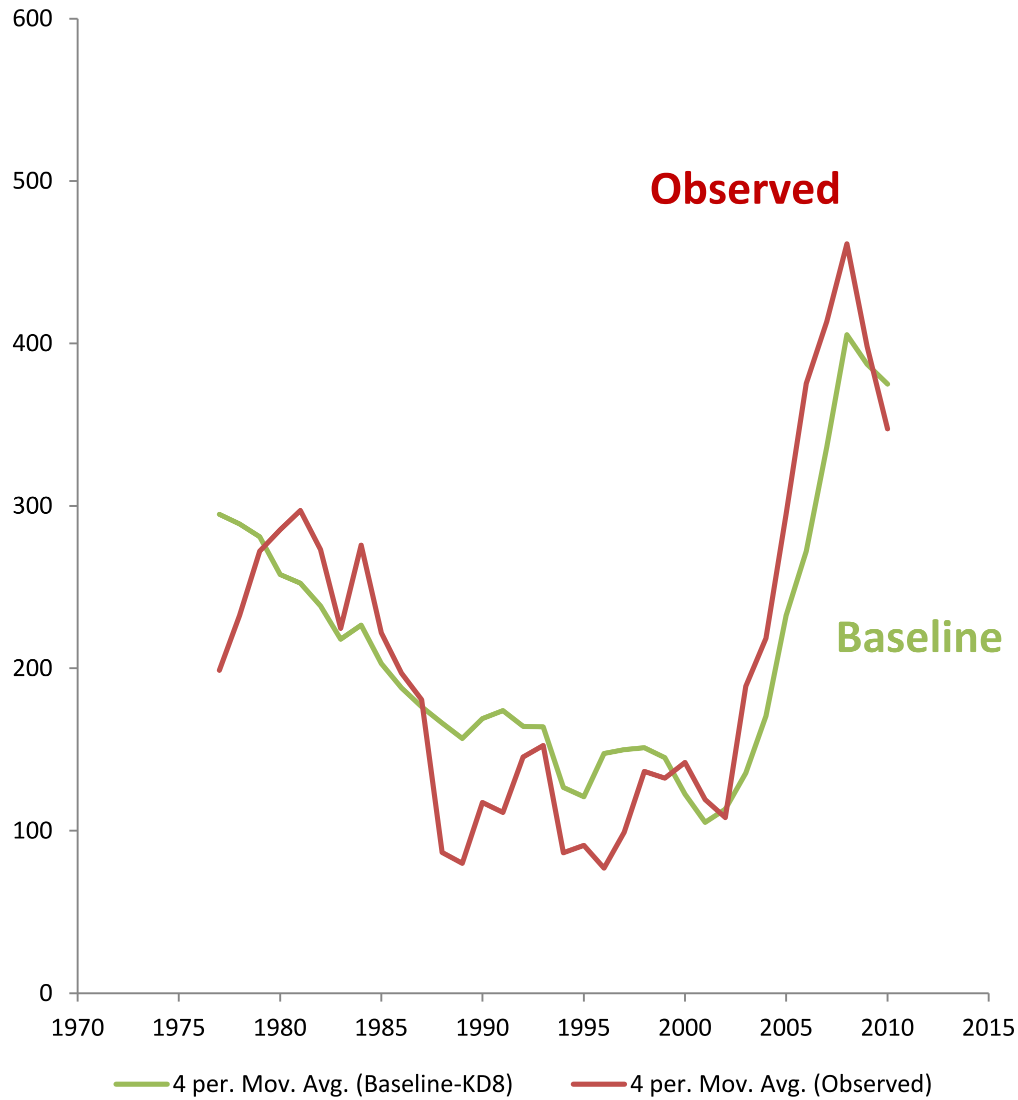
Random weather scenario



Reversed weather scenario



Simulated SRP Load

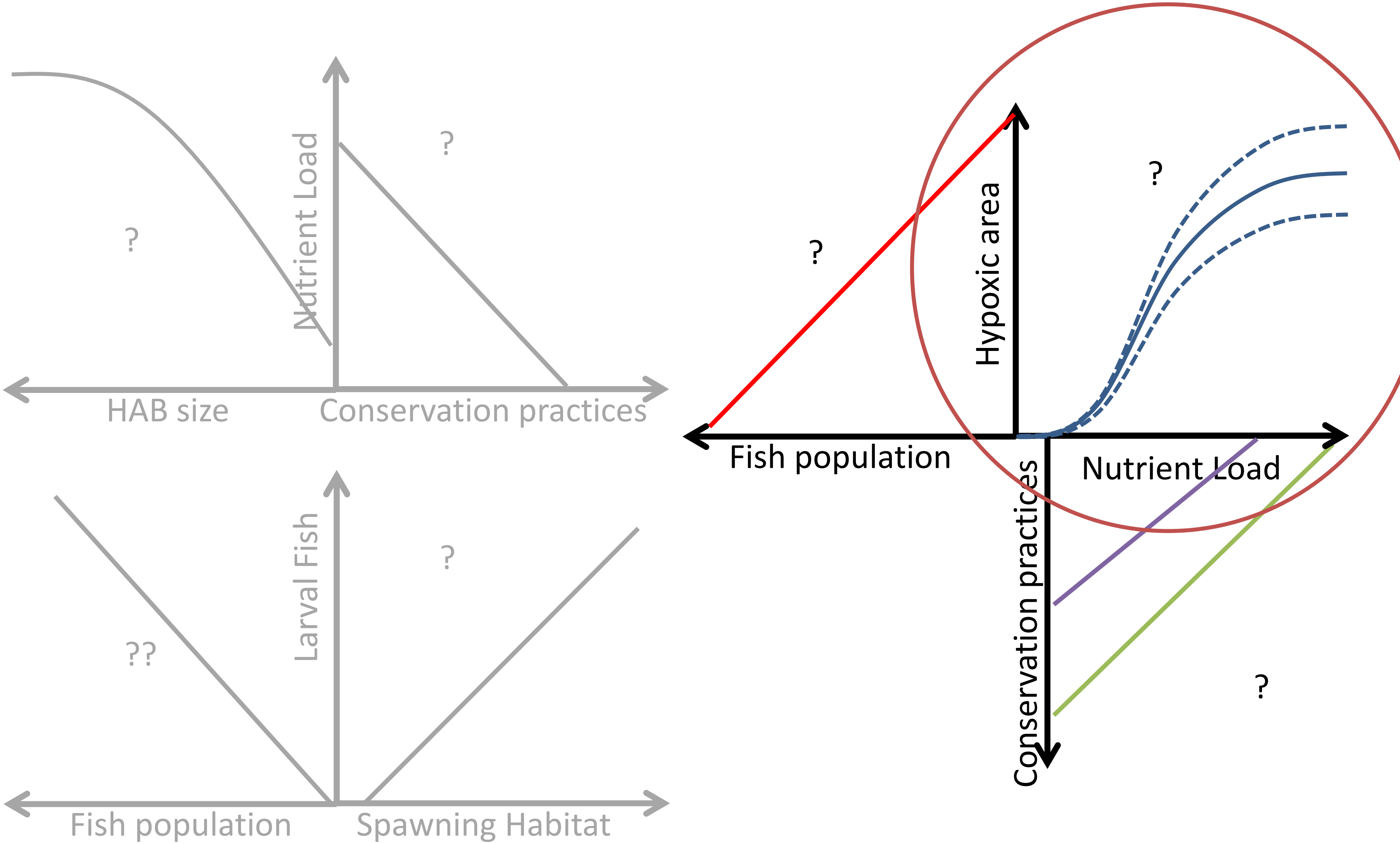


Watershed appears more vulnerable to weather impacts in recent years.

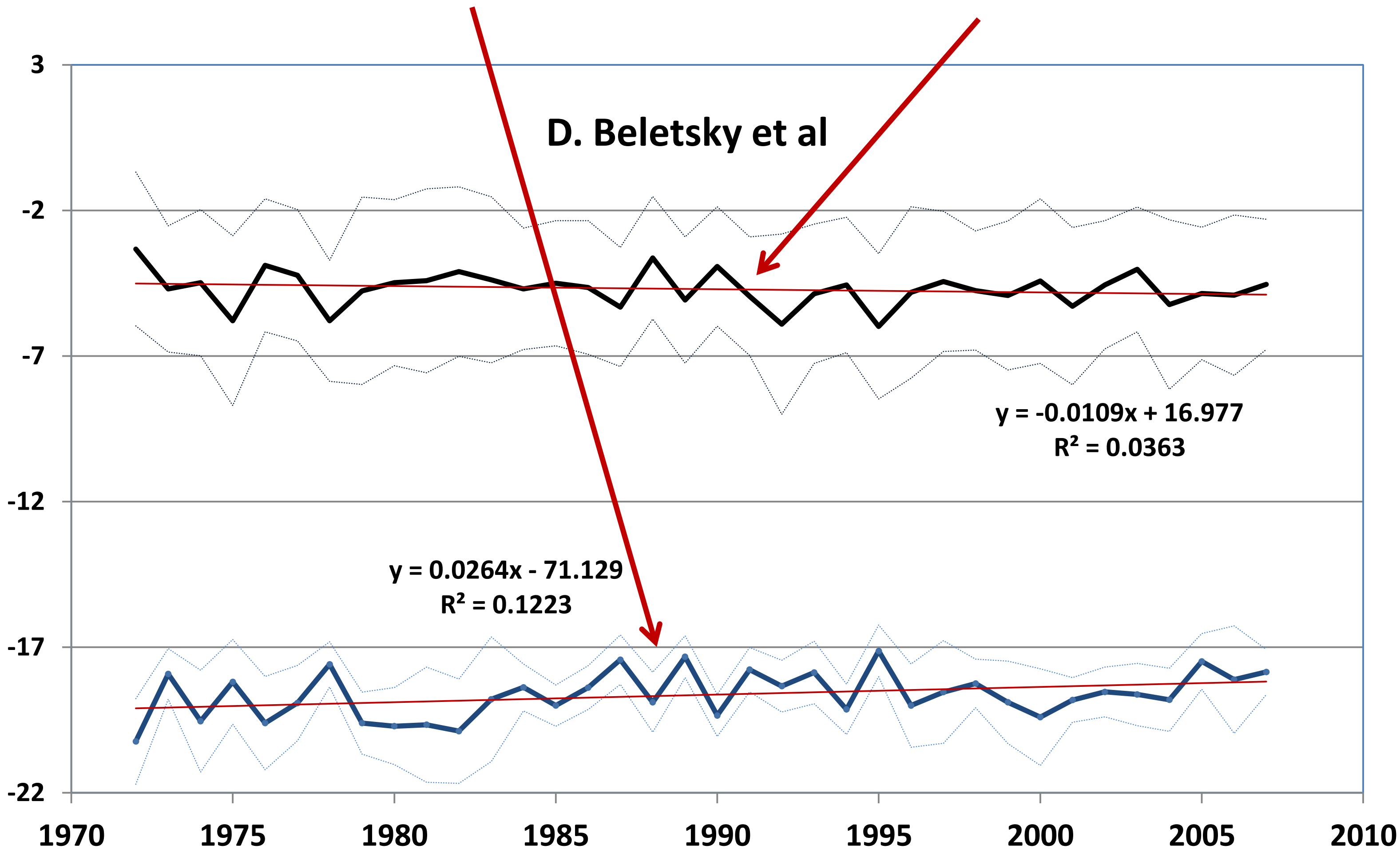
Soil P accumulation and tillage and fertilizing practices appear to underlie the weather driver.

Change in overall fertilizer rates shift load but do not seem to drive the pattern.

Three models



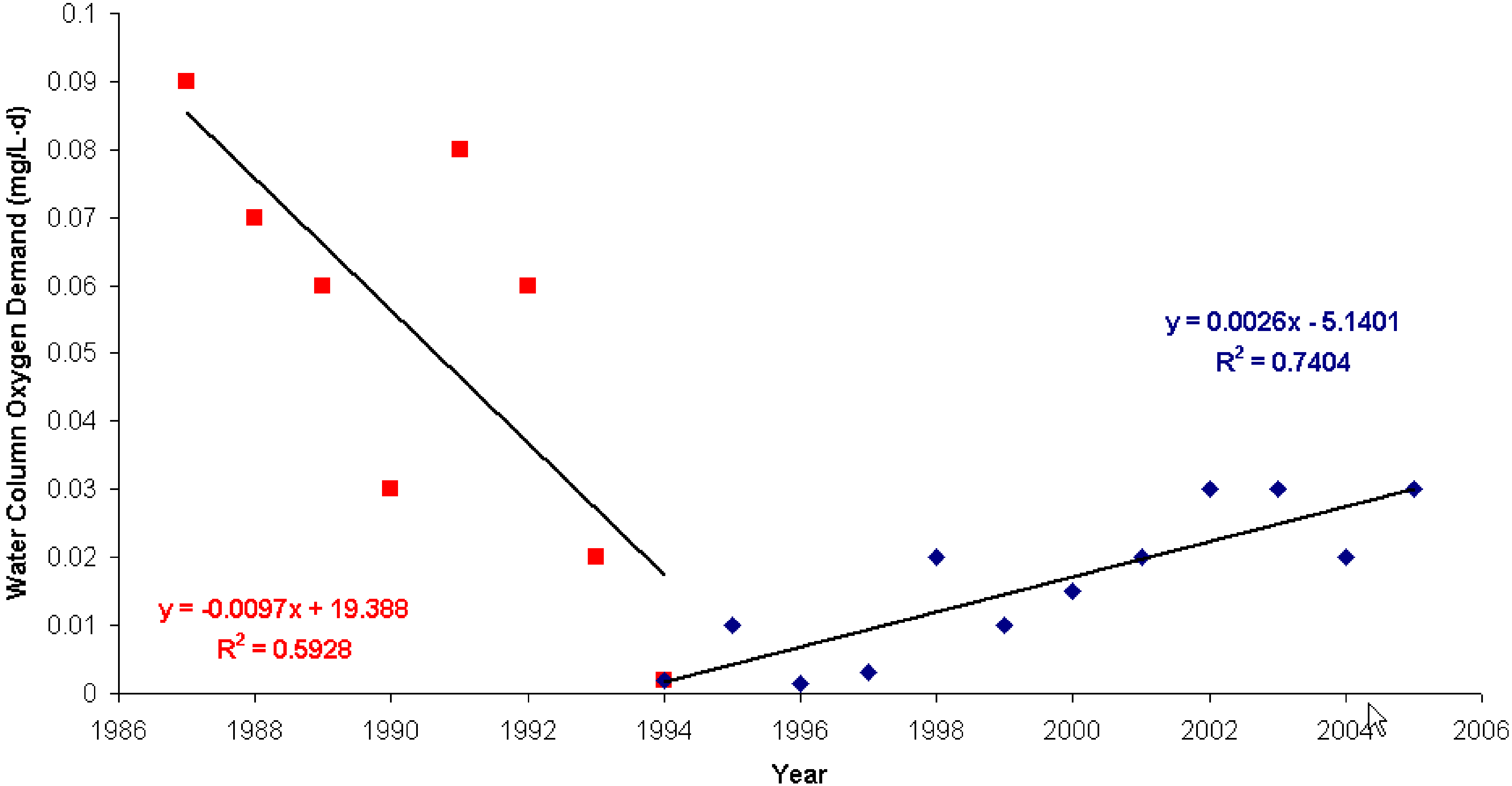
Thermocline Depth and Stratification Strength



No clear evidence through 2005

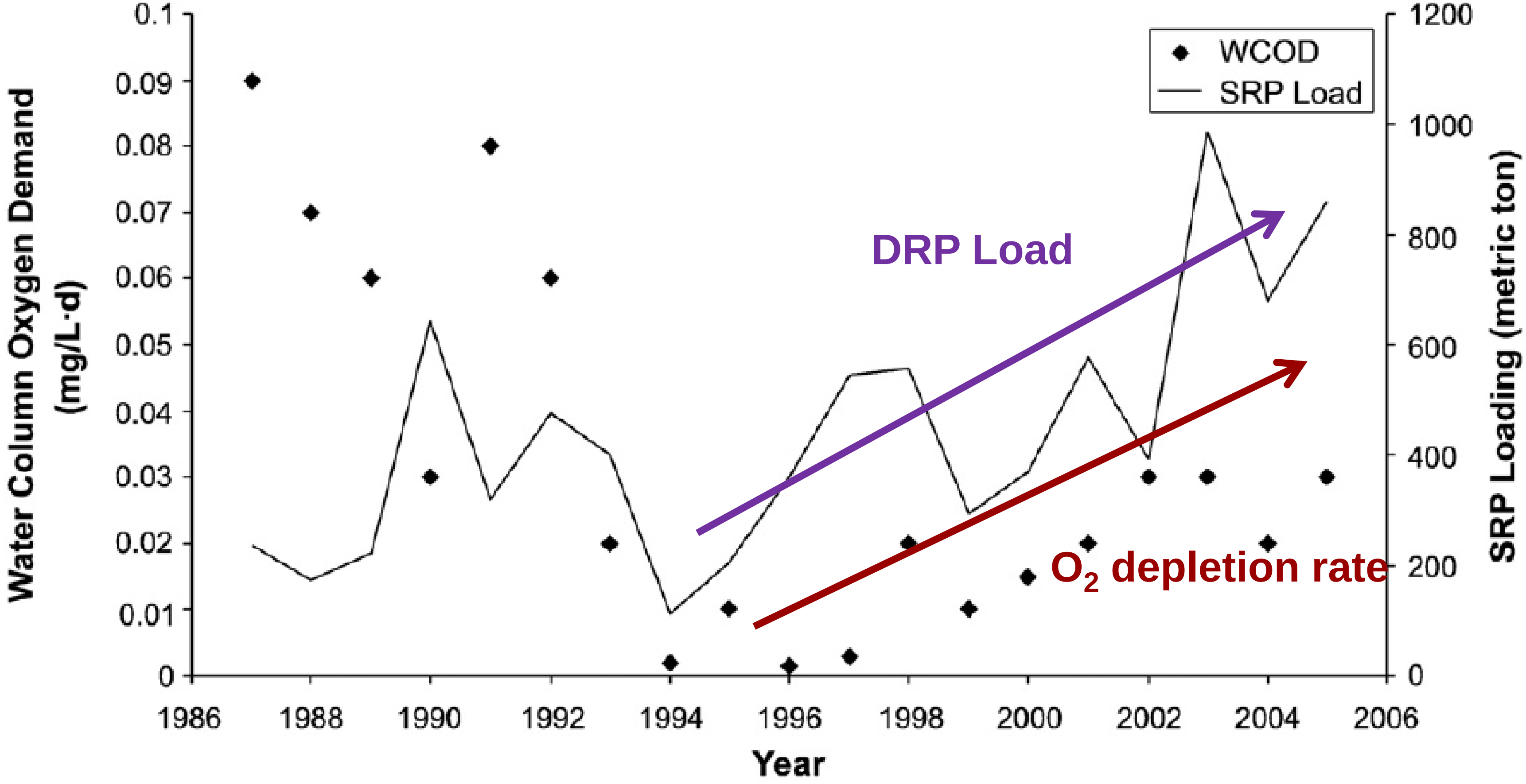
Rucinski et al. 2010

Water Column Oxygen Depletion Rate

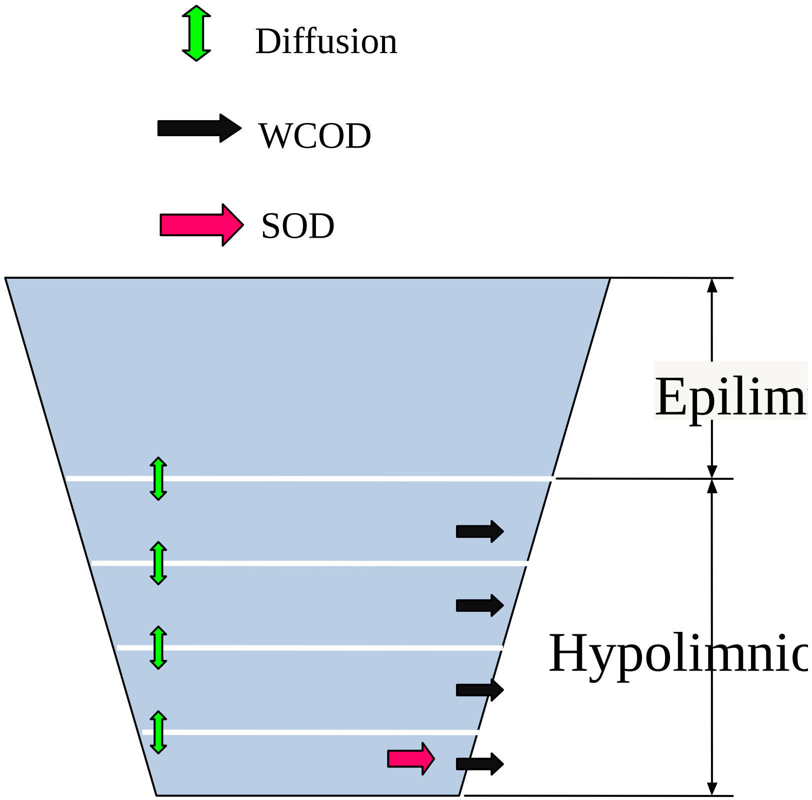


Rucinski, et al 2010

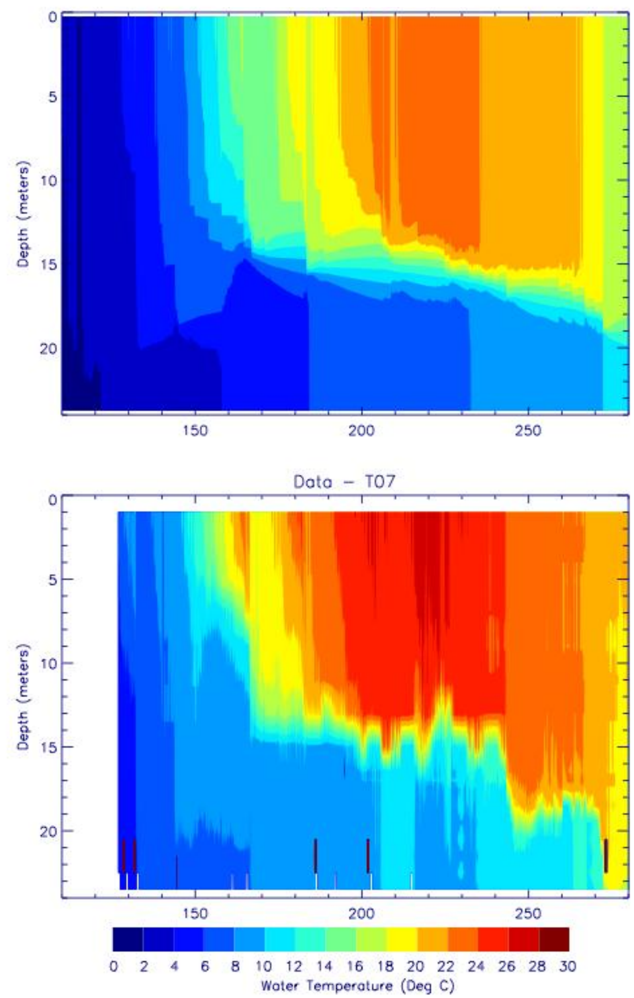
Water Column Oxygen Depletion Rate



Build Mixing Model



2005

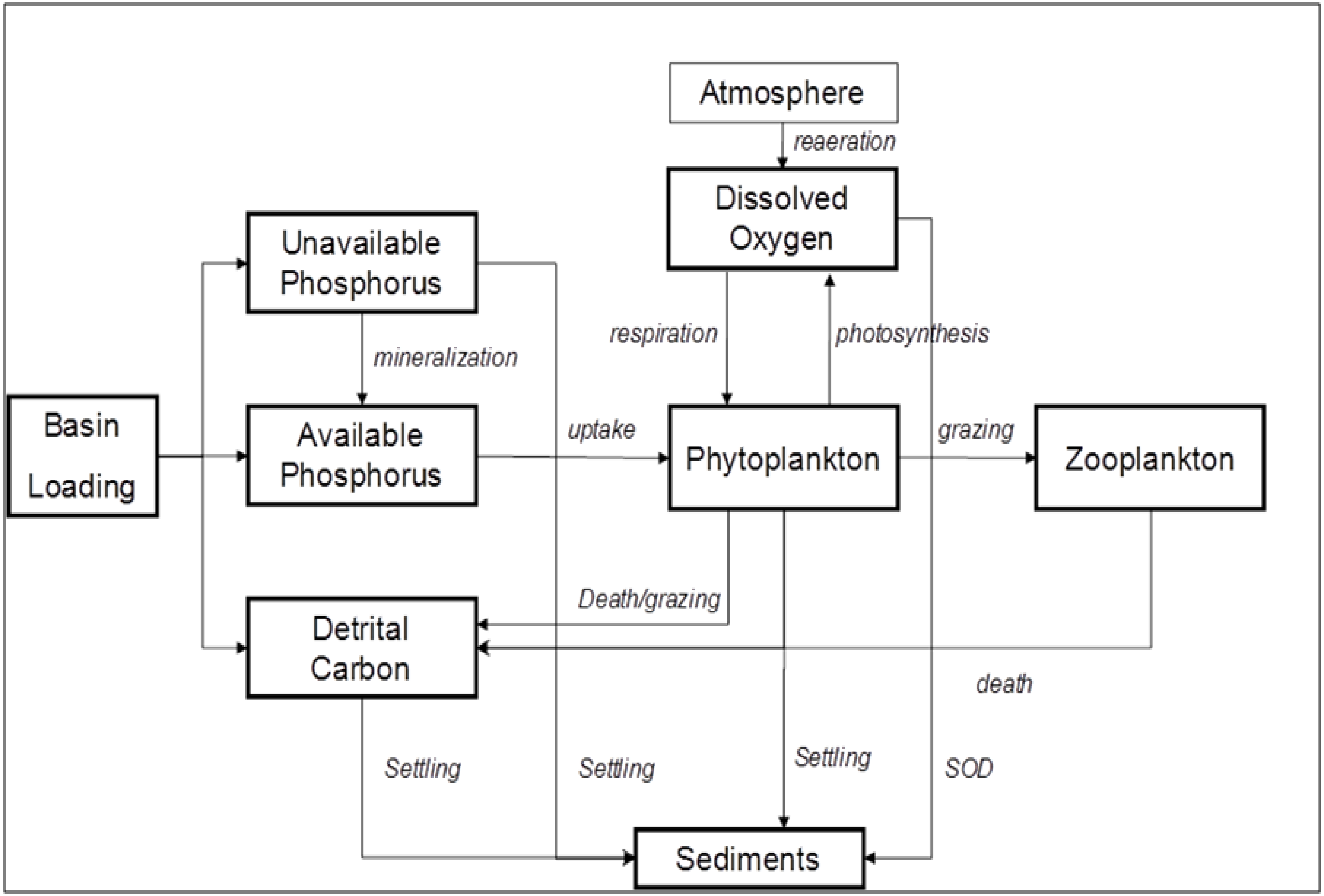


Model

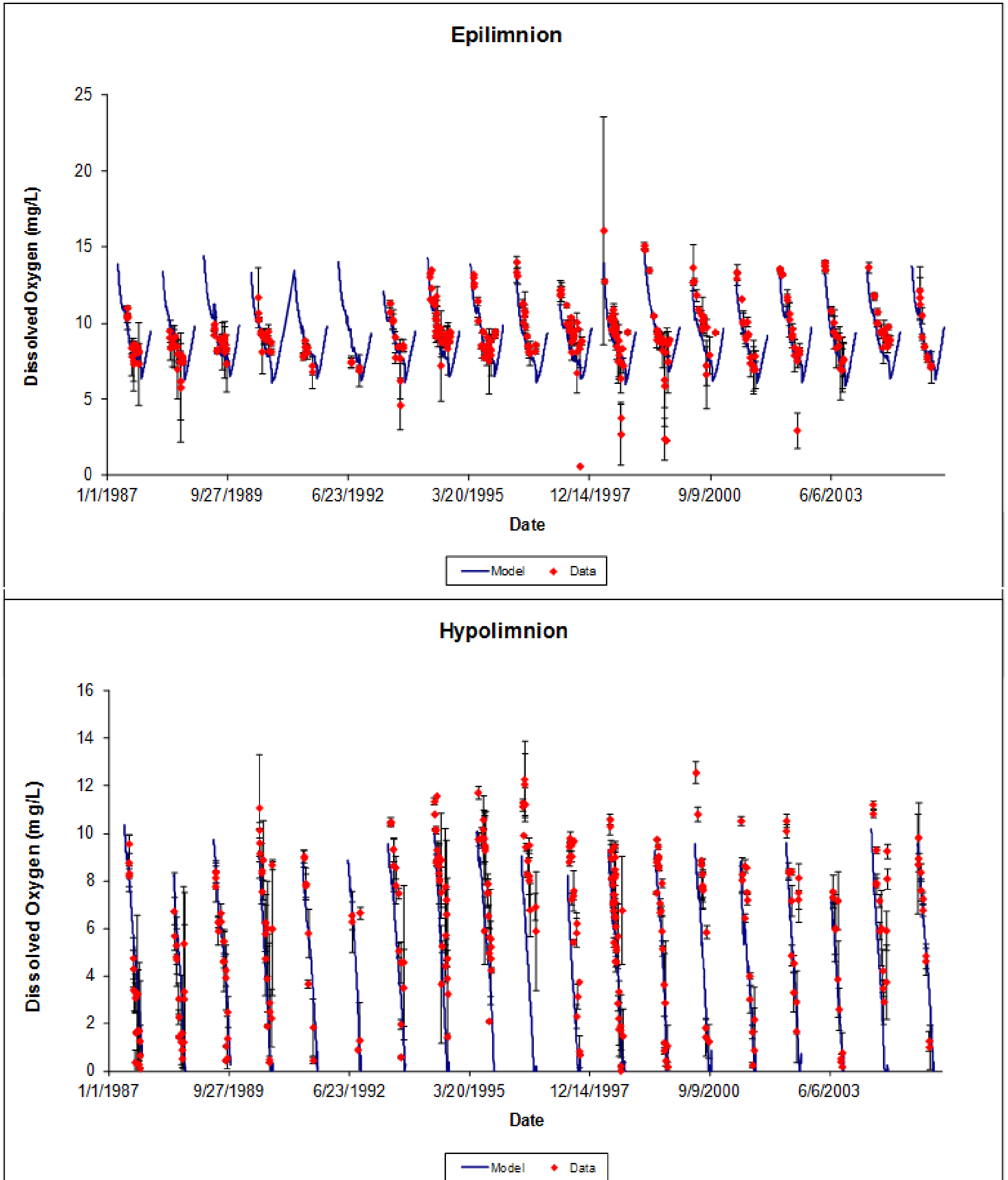
Data

Rucinski et al. 2010

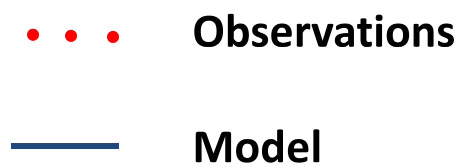
Eutrophication Model



Rucinski et al. 2013



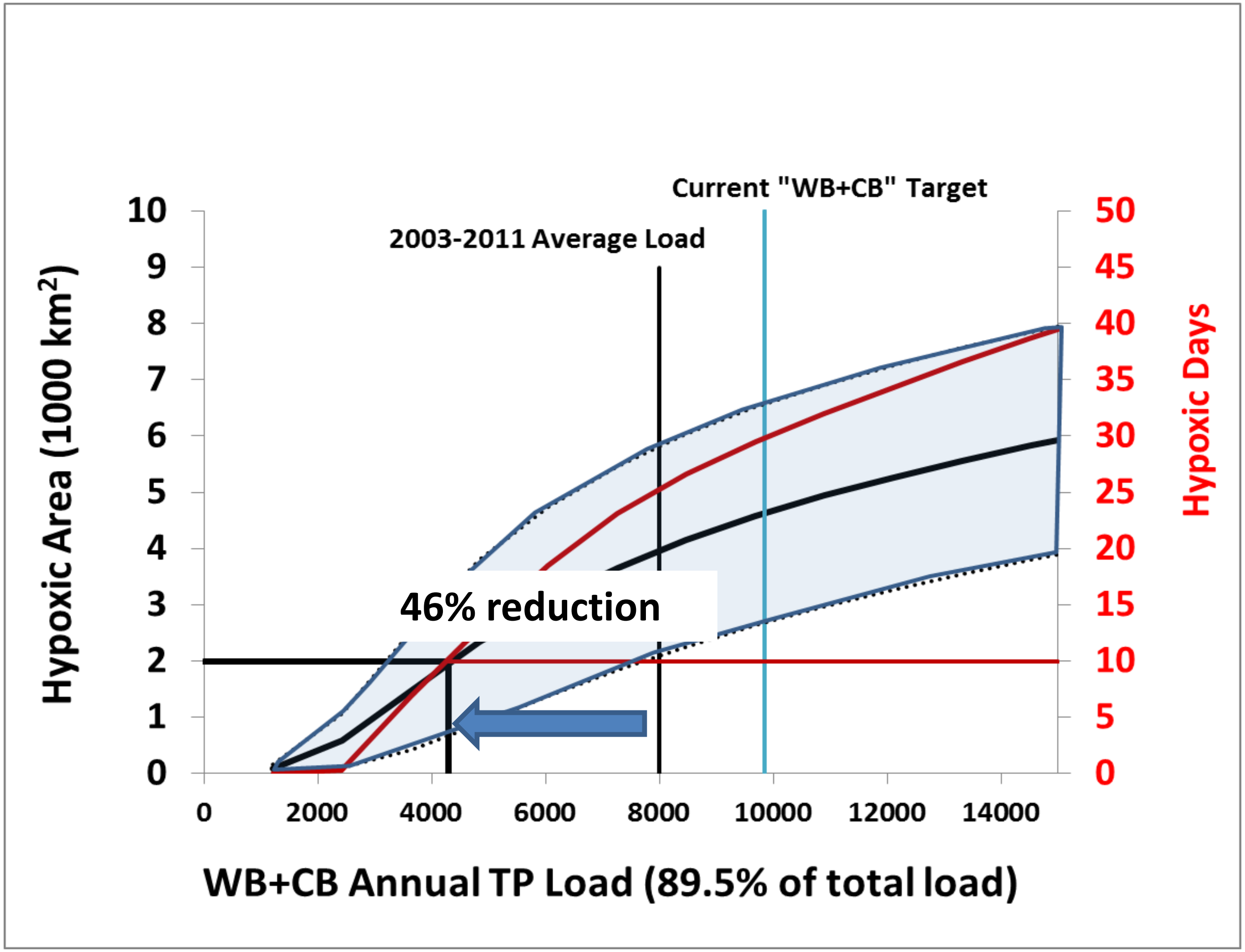
Model Calibration



Rucinski et al. 2013

Model-derived Response Curve

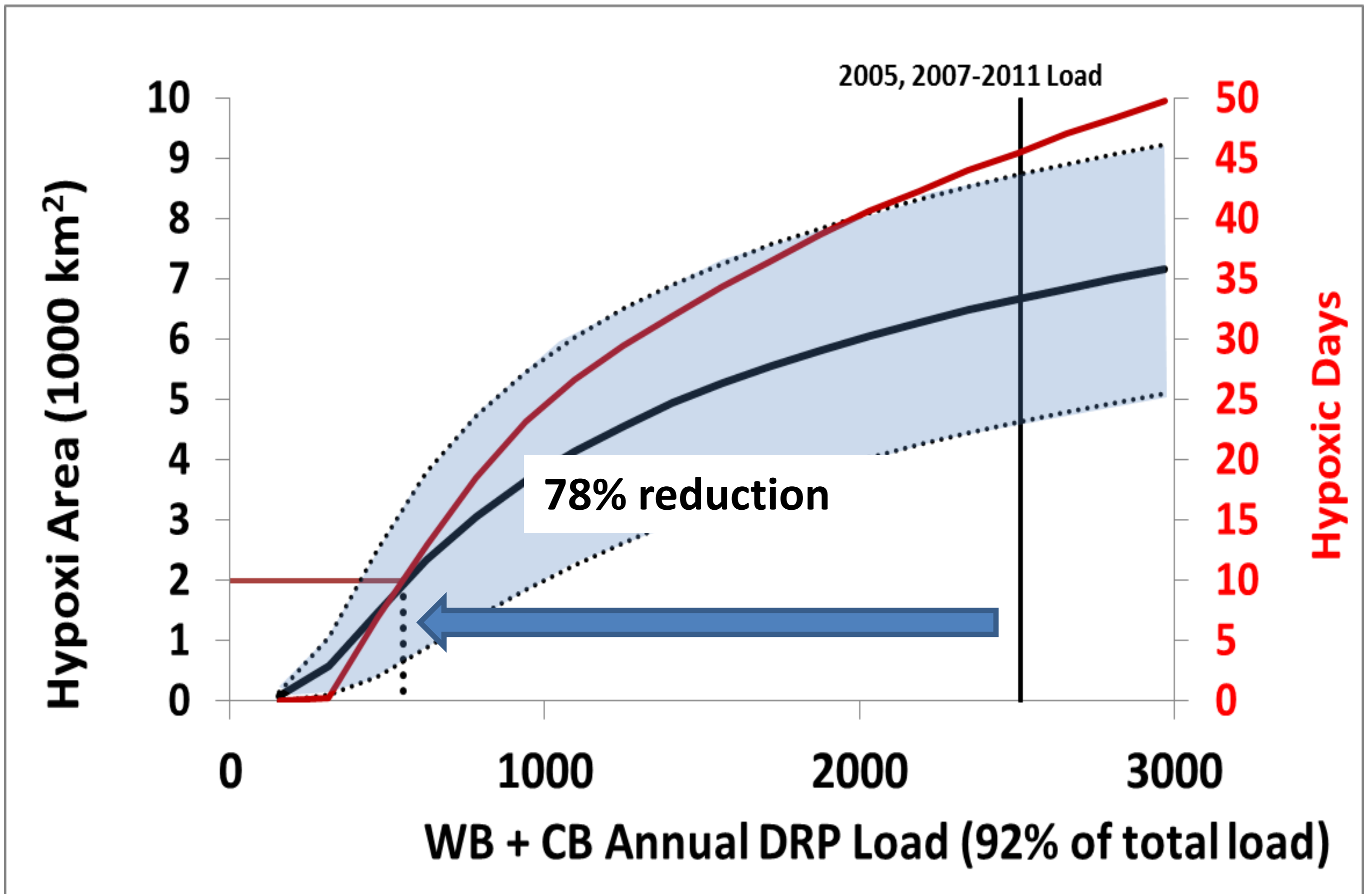
Envelop encompasses interannual weather variability



Scavia et al. in review

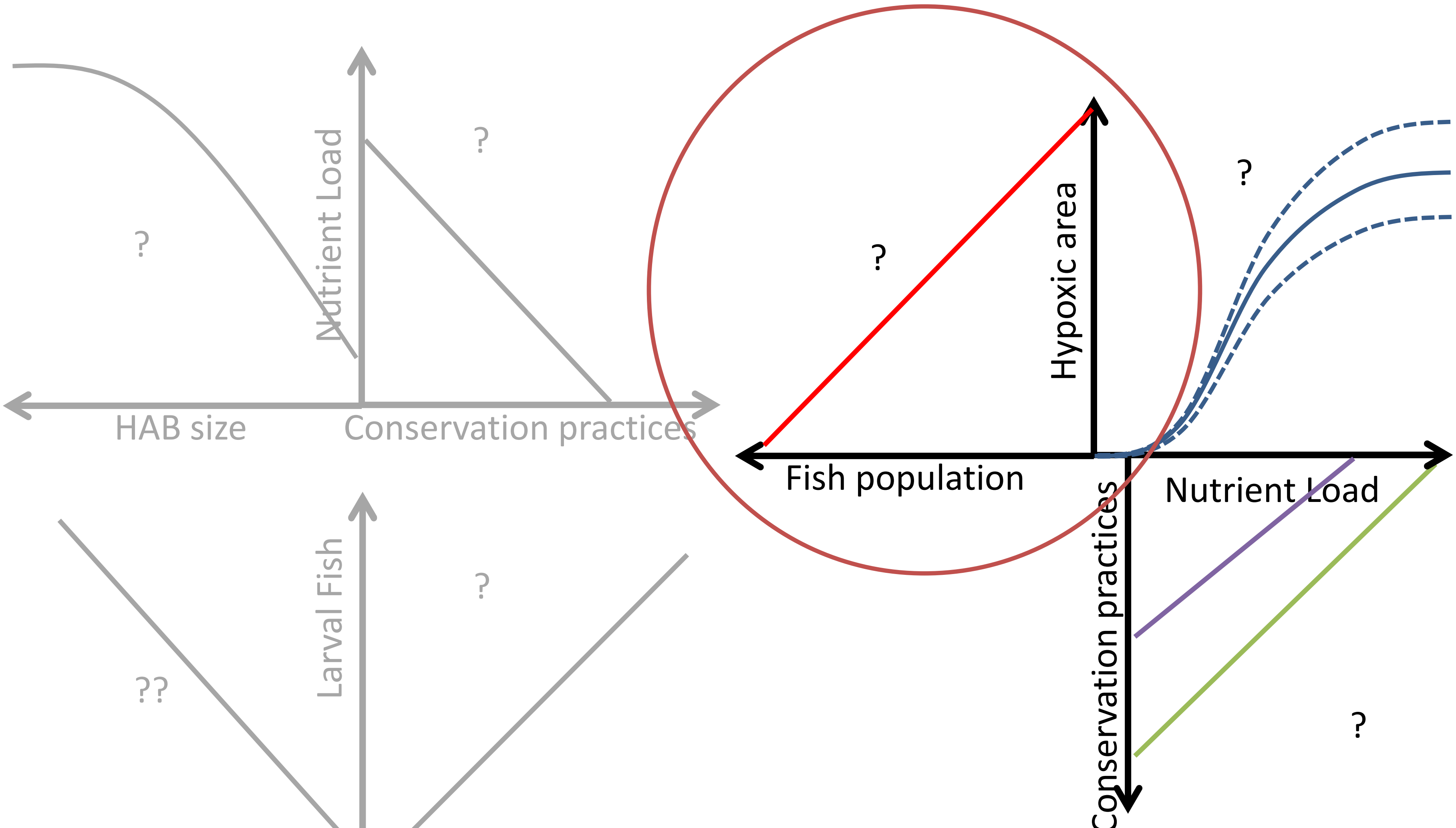
Model-derived Response Curve

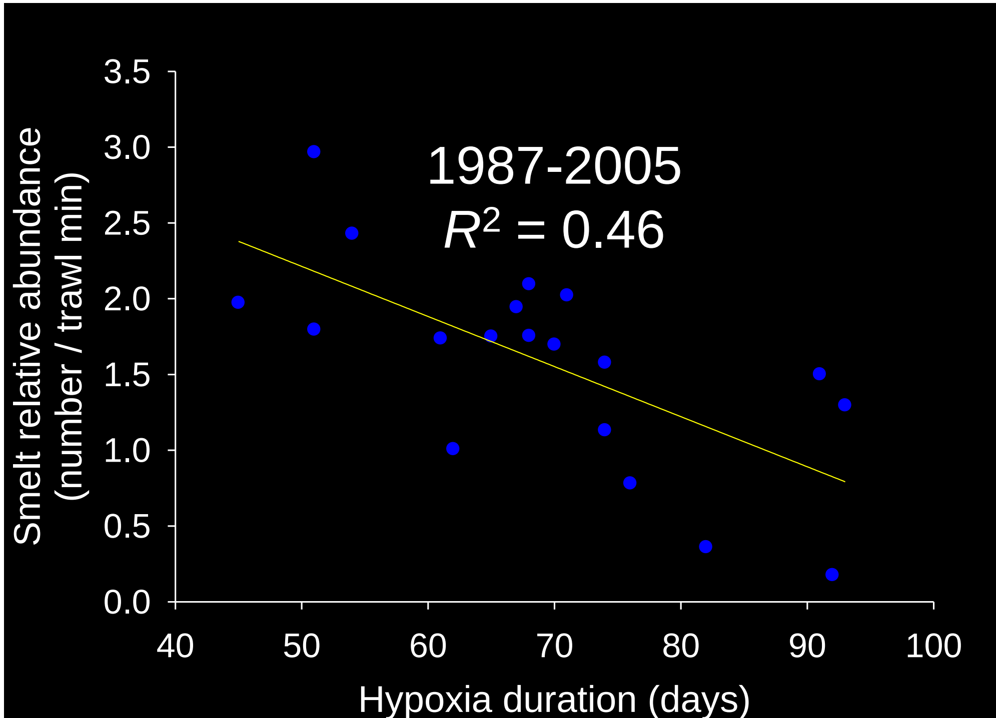
Based on Dissolved Reactive Phosphorus (DRP)



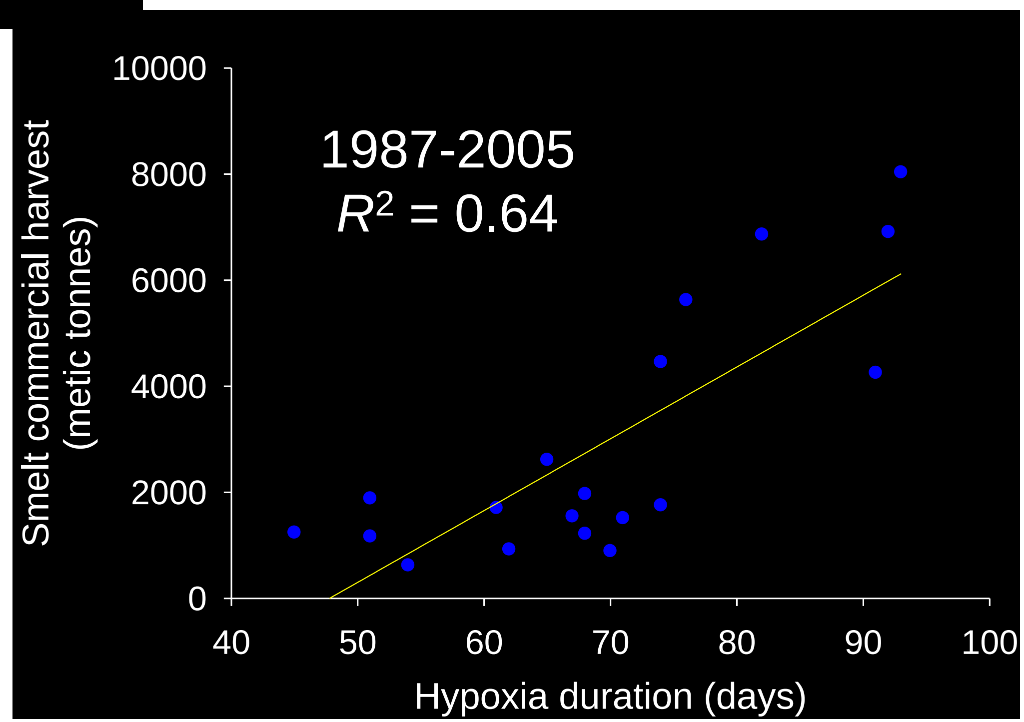
Scavia et al. in review

Three models



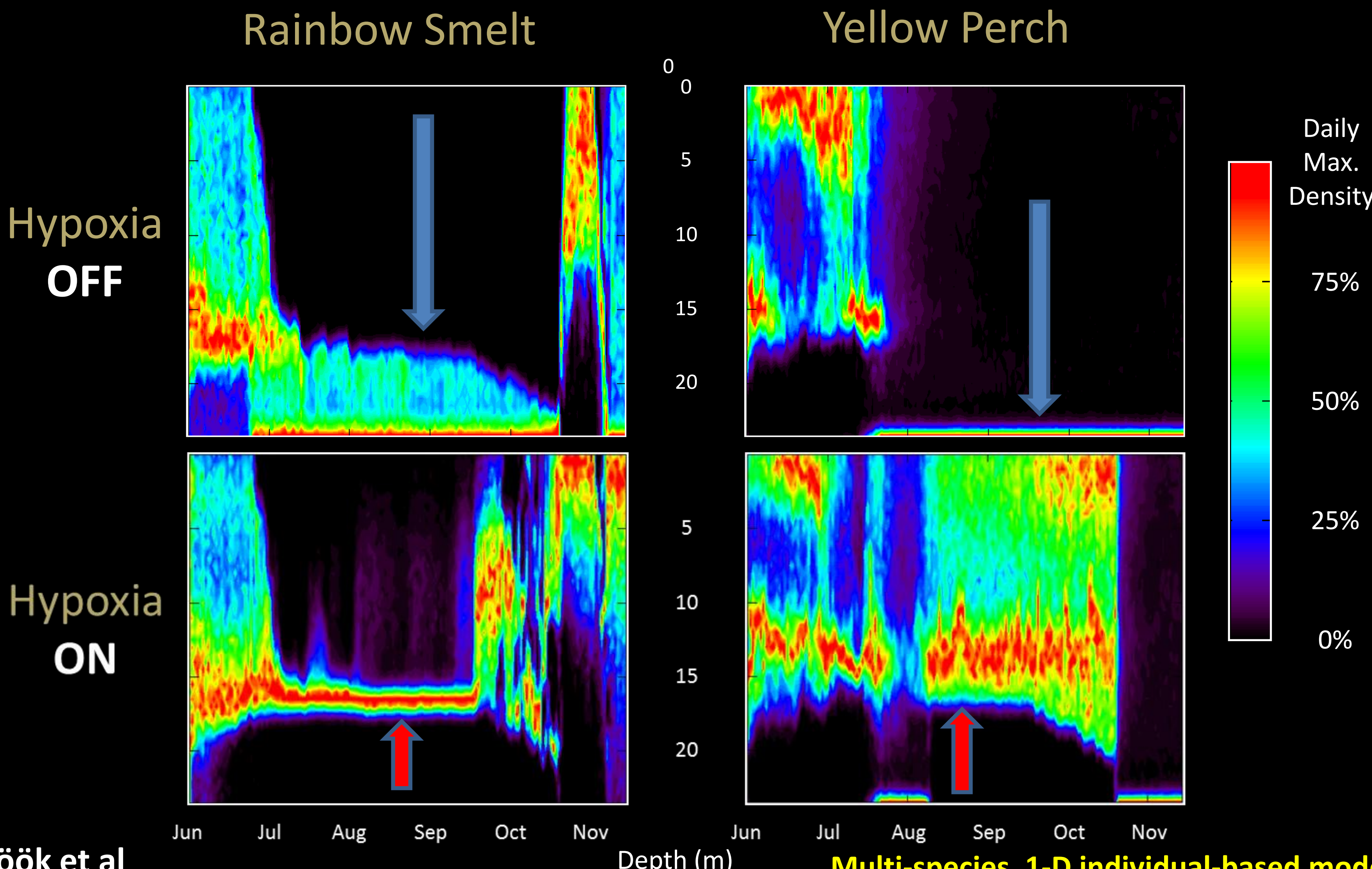


Smelt: Commercial Fisheries
Hypoxia: Water Quality Model



Ludsin, Pangle et al.

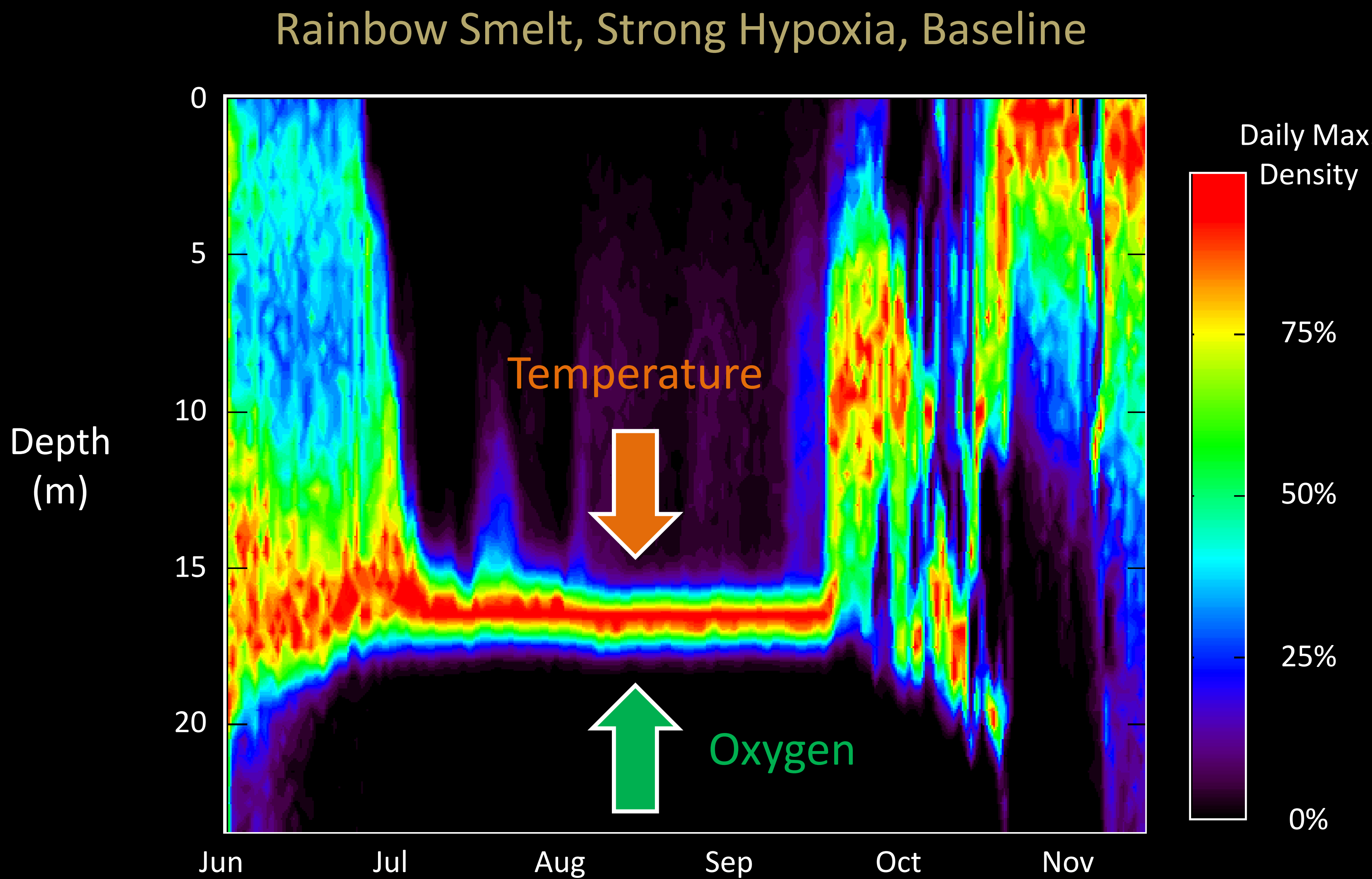
Vertical Distributions under Strong Hypoxia



Höök et al

Multi-species, 1-D individual-based model

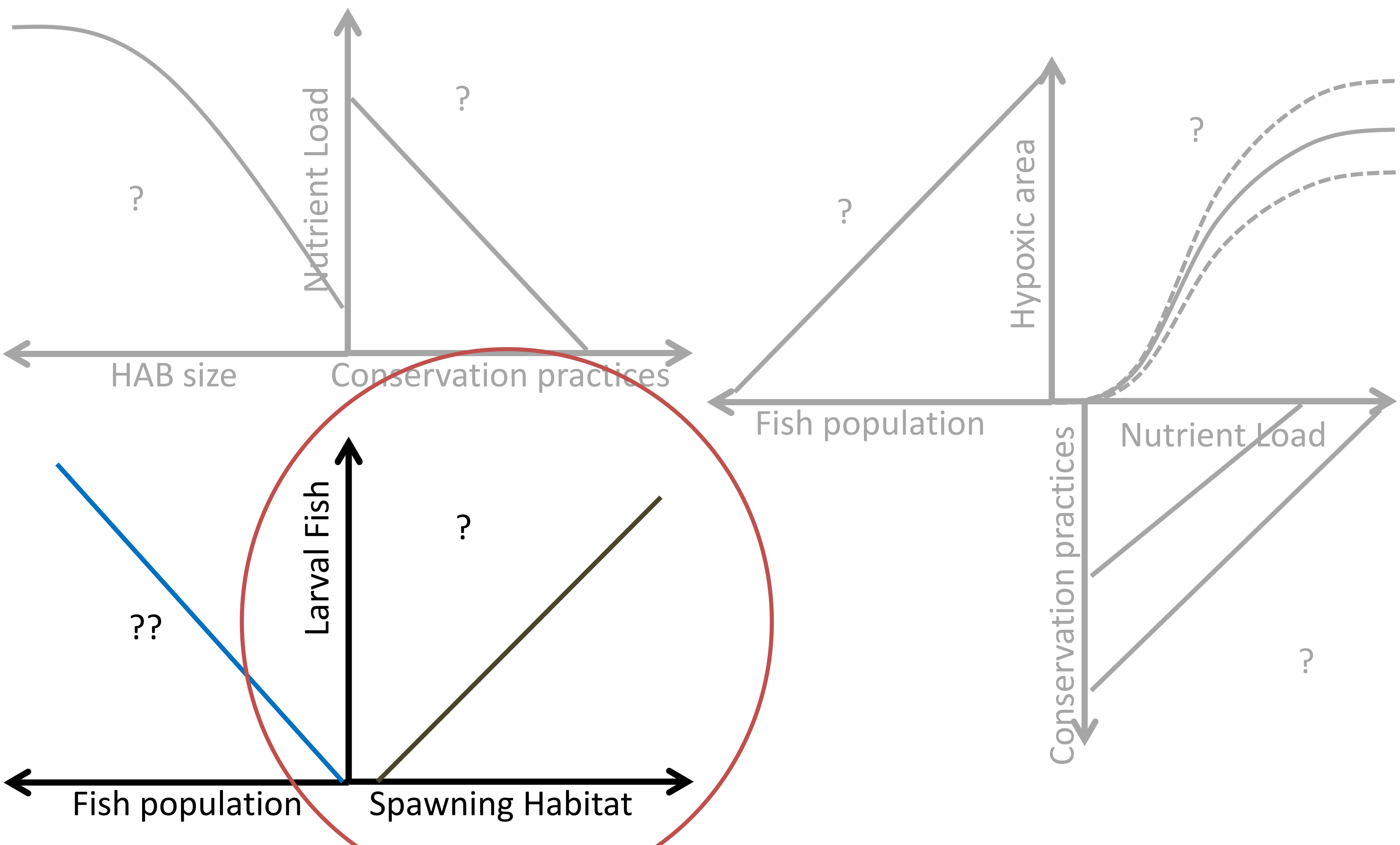
Oxy-thermal Squeeze



Höök et al

Multi-species, 1-D individual-based model

Three models



Problem Statement

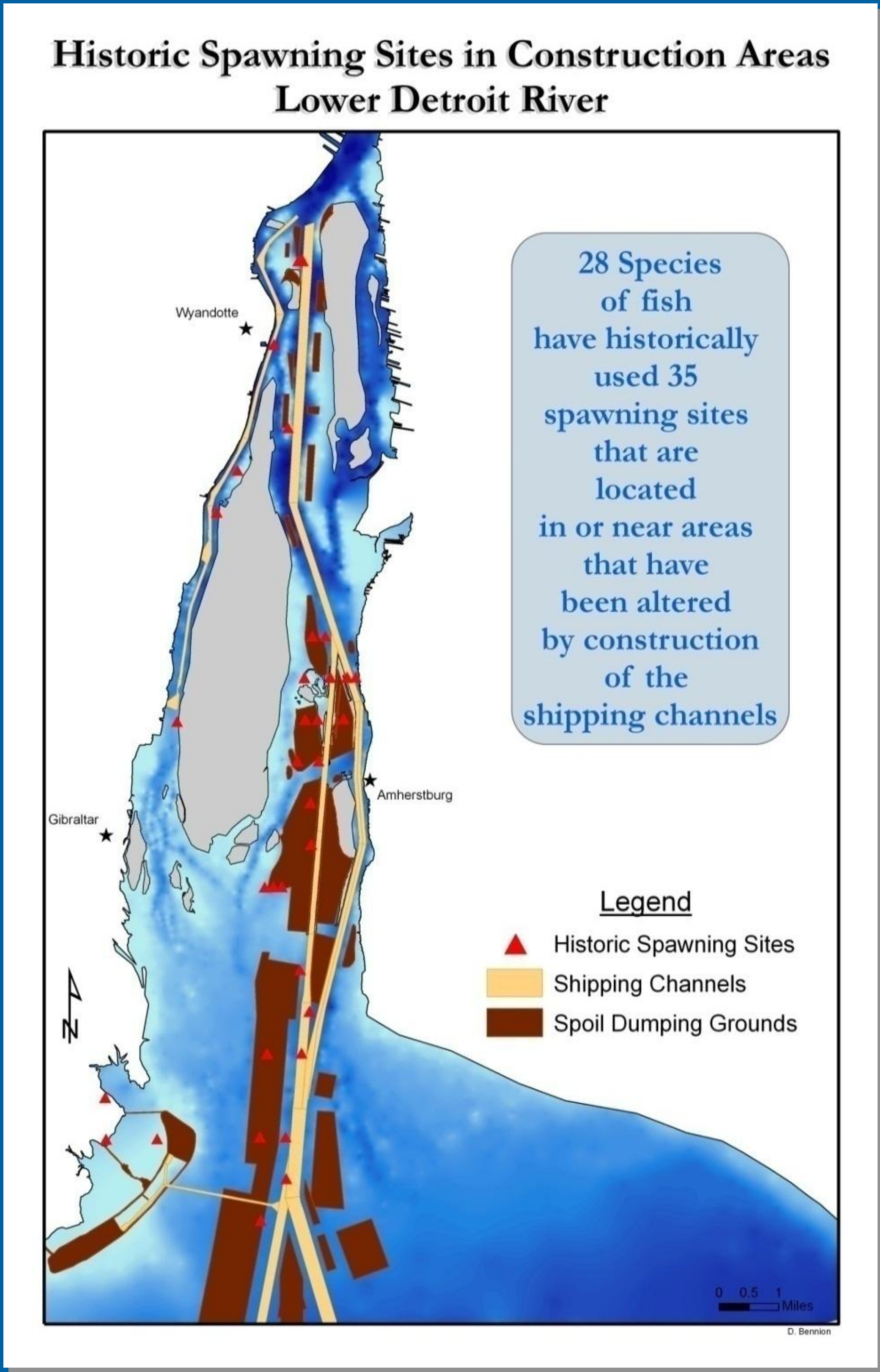
Major habitat degradation

- Riparian development / urbanization
- Industry and associated pollutants
- Dredging and channel modification
- Wetlands loss
- Exotic species

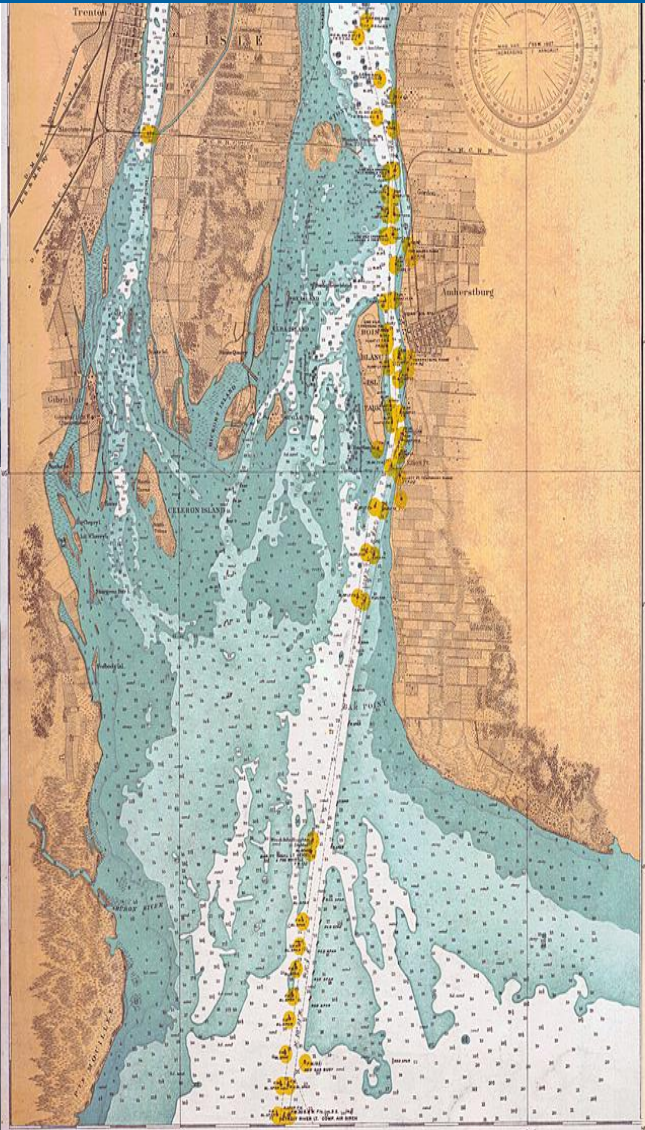
Loss of habitat

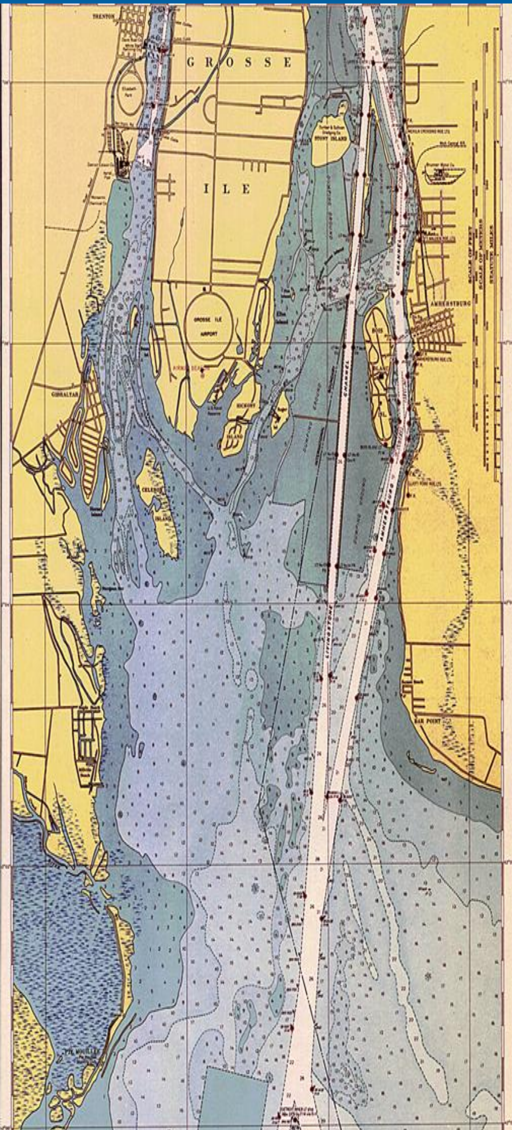
- Removed, inaccessible, disconnected

USGS



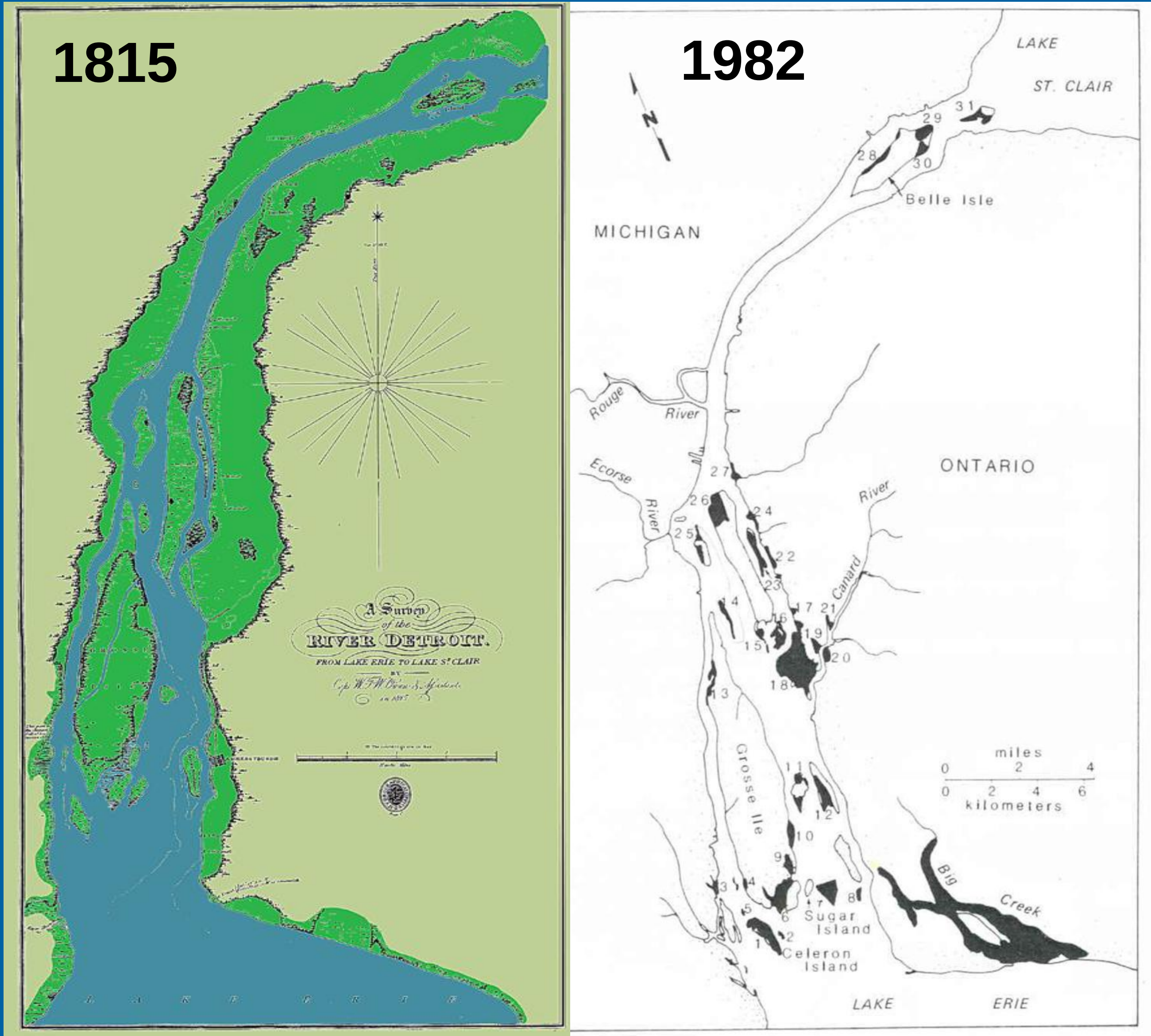
Habitat Loss in the St. Clair –Detroit Rivers System



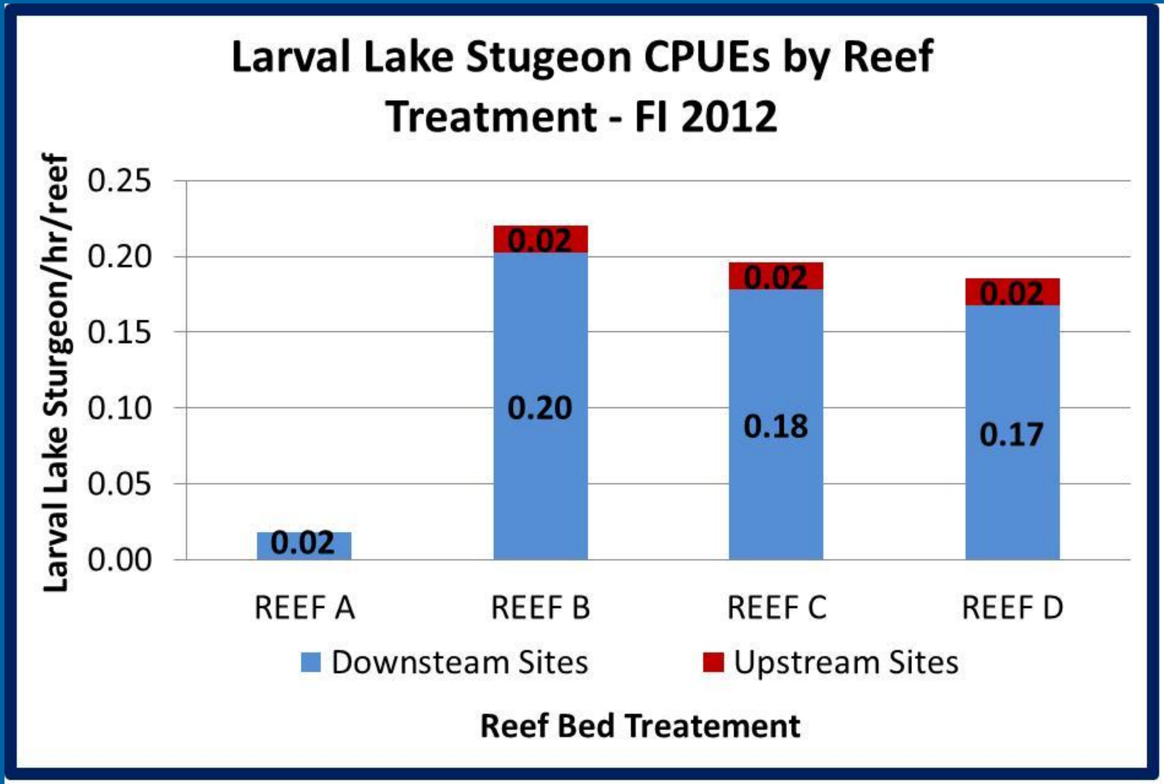


Habitat Loss in the St. Clair –Detroit Rivers System

Lost 97% of coastal wetlands



Post Construction Monitoring Fighting Island Reef

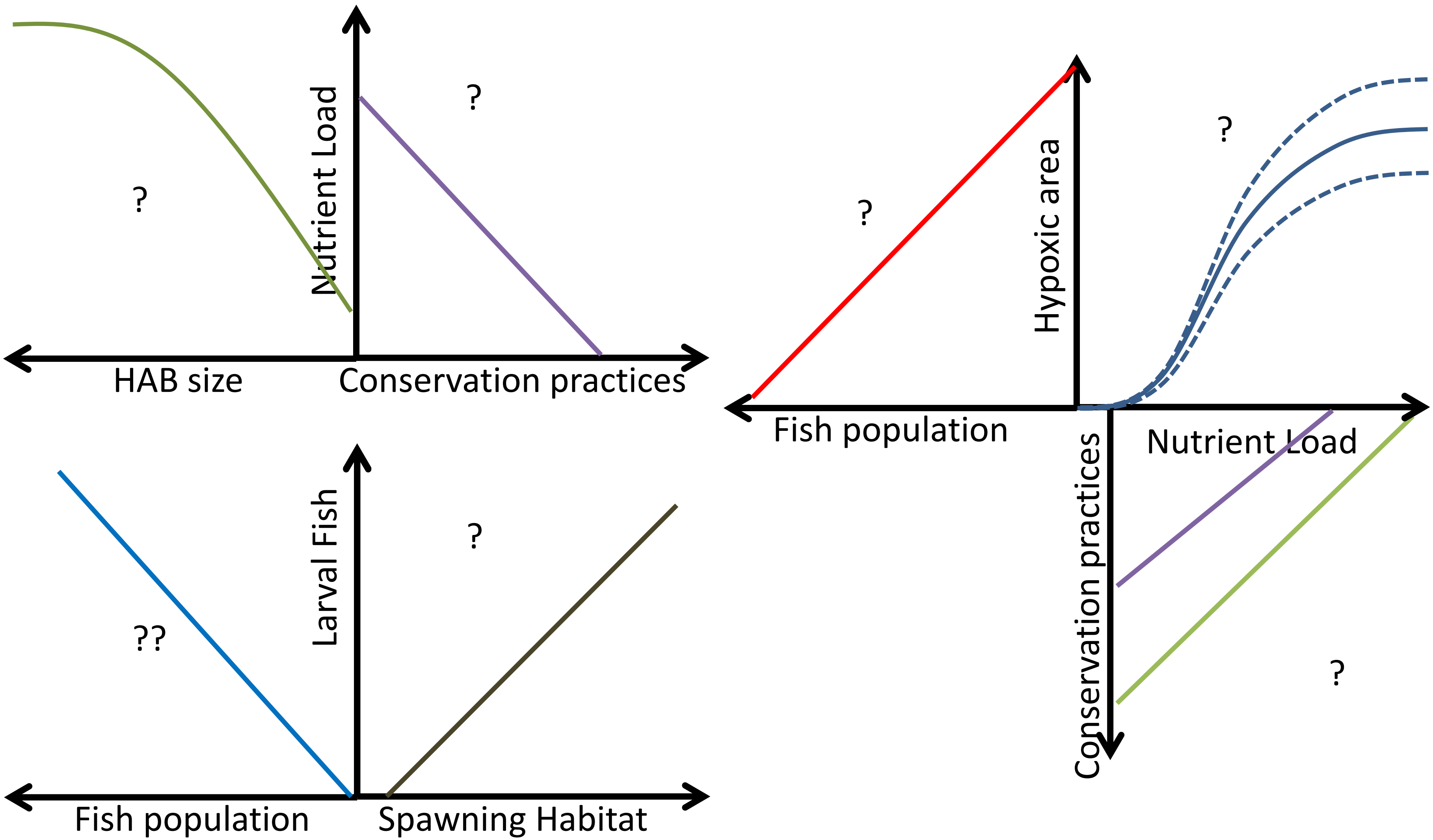


CPUEs (larval sturgeon/sampling hour) for sites upstream and downstream of reef beds A-D, and total CPUEs for reef beds A-D. Upstream= red, Downstream = blue.

USGS

From Bouckaert 2013

Three models



Four goals

- An organizing method for scientific information
- Both in lake and external loading changes matter
- Form of phosphorus matters
- Multiple causes and multiple effects must be considered to understand the system

USGS